NITRIFICATION INHIBITOR EFFECTS ON POTATO YIELDS AND SOIL INORGANIC NITROGEN

By

HARRIS WARTHMAN MARTIN

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I dedicate this work to my children Rachel and Stan, who have often played quietly so that daddy could work on his dissertation.

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By

Harris Warthman Martin

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Rapid loss of applied N from soils may result after nitrification of NH_4^+-N to NO_3^--N. Nitrification inhibitors should reduce N losses from leaching and denitrification, thus increasing N utilization by crops. The effects of nitrification inhibitors on soil inorganic N (SIN) concentrations, plant N uptake, and crop yield were evaluated. Dicyandiamide (DCD) and 2-chloro-6-(trichloromethyl)-pyridine (nitrapyrin) nitrification inhibitors were evaluated on potato (*Solanum tuberosum* L. cv. Atlantic). Treatments were combinations of N at 67, 134, and 202 kg ha^{-1}; DCD at 0, 5.6, and 11.2 kg ha^{-1}; nitrapyrin at 0.56 and 1.12 kg ha^{-1}; and isobutylidene diurea (IBDU) applied as one-third of the N. Studies were conducted on an Arenic Ochraqualf, a Grossarenic Paleudult, and a Grossarenic Paleaquult.

Tuber yields were increased 17% by use of nitrification inhibitors in one of five tests. At this location

severe leaching had occurred. Nitrification inhibitors increased leaf N concentrations at flowering in three of four tests. Tuber yields were higher with DCD than with nitrapyrin in three of five tests. Tuber yields increased with an increase in N from 67 to 134 kg ha^{-1} in three of three tests. In one test where severe leaching had occurred, tuber yields increased with an increase in N to 202 kg ha^{-1}. Nitrification was inhibited by nitrification inhibitors in all of four tests, and increased SIN concentrations in one. SIN concentrations in mid- and late-season were higher with one-third N as IBDU-N, than with nitrification inhibitors.

In a second study, DCD was applied to a fallow Typic Quartzipsamment at 0, 20, 40, and 60 kg ha^{-1} with urea at 200 kg N ha^{-1}. Dicyandiamide inhibited nitrification for 81 days. However, SIN concentrations were reduced with DCD. Residence half times of DCD in the 0 to 1.2 m depth were 61 to 66 days with 20 to 60 kg DCD ha^{-1}.

Use of nitrification inhibitors increased crop yields only under conditions where SIN concentrations were increased, N rates were 134 kg ha^{-1} or less, and leaching was severe. Inhibition of nitrification did not lead to increases in SIN concentrations in most experiments. Increases in potato yields with nitrification inhibitors did not occur in most experiments as SIN concentrations were not increased.

CHAPTER 1
INTRODUCTION

Nitrate is subject to greater leaching and denitrification losses from soil than NH_4^+. Nitrification, the natural transformation of NH_4^+ to NO_3^- by certain soil bacteria, promotes losses of N by denitrification and leaching out of the crop root zone. As a result, crops make inefficient use of fertilizer N. In addition, leaching of NO_3^- poses an environmental hazard.

It has been commonly assumed that inhibiting nitrification should reduce N losses from leaching and denitrification, increase N utilization by crops, and provide more even N nourishment of crops over longer periods of time than would otherwise be possible. If this is true, control of nitrification should lead to increased efficiency of N use with corresponding improvements in crop growth, yield, and quality. Dicyandiamide (DCD) and 2-chloro-6-(trichloromethyl)-pyridine (nitrapyrin) are two of a number of synthetic nitrification inhibitors that have been tested and made available commercially.

The objectives of this study were (1) to assess the effects of DCD and nitrapyrin on potato (*Solanum tuberosum* L. cv. Atlantic) tuber yield, crop quality (tuber specific

gravity and tuber grade proportions), plant biomass, plant N concentration, and N uptake in Northeast Florida; (2) to assess the effectiveness of DCD and nitrapyrin as inhibitors of nitrification in sandy coastal plain soils of Northeast Florida, as measured by their effects on extractable soil inorganic NH_4^+-N, NO_3^--N, and the total of these; (3) to compare the effects of DCD to those of nitrapyrin, and to compare the effects of the two inhibitors with those of isobutylidene diurea (IBDU), a slow release N source; (4) to determine the extent to which N rate, inhibitors, and IBDU effects on plant response parameters can be attributed to the effects of these treatments on total soil inorganic N concentrations; (5) to study DCD's nitrification inhibiting effect and the fate of DCD in the soil, by measuring the effects of DCD on soil inorganic N concentrations and movement, and DCD movement and loss in a fallow, deep sandy soil; and (6) to contribute to an understanding of why nitrification inhibitors often do not increase crop yield.

CHAPTER 2
LITERATURE REVIEW

Nitrification Inhibitors

Introduction

Numerous compounds have been proposed for regulating nitrification in soils, including organic and inorganic compounds, pesticides, chelating agents, and plant products. A number of these are manufactured and patented in the USA, Japan (Ranney, 1978), and Europe. Of the number of inhibitors mentioned in the literature over a period of 20 years (Ranney, 1978), only nitrapyrin, DCD, and to a lesser extent 2-amino-4-chloro methyl pyrimidine (AM) have been tested thoroughly (Slangen and Kerkhoff, 1984). The inhibitors of nitrification are effective if they retard one or more steps in the following chain of microbial reactions:

$$NH_4^+ \xrightarrow{\underline{Nitrosomonas}} \text{hydroxylamine} \rightarrow$$
$$\text{nitroxyl?} \rightarrow \text{nitrohydroxylamine} \rightarrow \qquad [1]$$
$$NO_2^- \xrightarrow{\underline{Nitrobacter}} NO_3^- \text{ (Hauck, 1972).}$$

The ideal nitrification inhibitor should inhibit <u>Nitrosomonas</u>, not <u>Nitrobacter</u>, since such inhibition would result in accumulation of NO_2^-. It should also be nontoxic

to other soil organisms, fish, mammals, and crops and be safe in the environment. It should be able to move with the fertilizer or fertilizer solution, that is, be effective throughout the fertilizer reaction zone. Rapid movement through soils because of high vapor pressure or little movement because of low vapor pressure or strong sorption could lead to poor performance. The ideal nitrification inhibitor should be sufficiently persistent in its action so that nitrification is inhibited for an adequate period of time, usually from several weeks to months. The chemical should be a low cost additive to fertilizer (Hauck, 1972; Turner and MacGregor, 1978; Sampei, 1972).

Chemical Properties of the Inhibitors

Nitrapyrin. Nitrapyrin was first introduced in 1962 by C.A.I. Goring of the Dow Chemical Company (Goring, 1962a, 1962b). This product stimulated the interest of quite a few researchers in several countries, resulting in many studies and published papers. As of 1981, nitrapyrin was used on >1 million hectares of agricultural land annually in the USA (Ashworth and Rodgers, 1981). Nitrapyrin is the principal nitrification inhibitor used commercially in North America, though 5-ethoxy-3-trichloromethyl-1,2,4-thiadizole (terrazole) is also used widely (Hergert and Wiese, 1980).

Nitrapyrin is a white crystalline solid with a molecular weight of 230.9 atomic units and a melting point of 62 to 63°C (Goring, 1962a, 1962b). It is soluble in liquid NH_3

but insoluble in water; thus it has to be dry-mixed with solid fertilizers or applied directly, preferably as a solution or emulsion (Turner et al., 1962). It has the following structure (Figure 2-1):

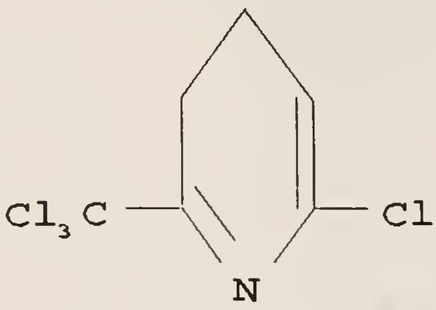

Figure 2-1. The structure of nitrapyrin, or 2-chloro-6-(trichloromethyl)-pyridine (N-Serve).

Nitrapyrin is marketed as "N-Serve 24 nitrogen stabilizer" (a.i. 240 g L^{-1}) and "N-Serve 24E nitrogen stabilizer" (a.i. 240 g L^{-1}) with an emulsifier (Slangen and Kerkhoff, 1984).

Dicyandiamide. The ability of DCD to inhibit nitrification has been observed by Brioux (1910), Nommik (1958, 1959), Reddy (1964a, 1964b), Rathstack (1978), Vilsmeier and Amberger (1978), Guster (1981), Kick and Poletschny (1981), Ashworth and Rodgers (1981), and others. The advantages of DCD over nitrapyrin for a given application, are due primarily to its different physical properties and its N content. While nitrapyrin has a low water solubility, high vapor pressure, high corrosiveness, and leaves a residue of chloropicolinic acid, DCD is a solid at room temperature and

can be processed as powder, granules, or pellets. It has a relatively high solubility in water, contains 16% N, and breaks down to NH_4^+ and CO_2, leaving no synthetic organic residues. Part of its cost can be justified by its N content (Amberger, 1981a; Kick and Poletschny, 1981; SKW, 1973). Because of these characteristics, DCD can be used as an additive to liquid, organic, or mineral fertilizers, surface coated on to, or incorporated into solid fertilizers containing NH_4^+ or urea, or applied alone to the soil (Amberger, 1984; Solansky, 1981; SKW, 1973). It requires no special equipment for its application. A brief review and discussion of agronomic properties of DCD and of the manufacture of DCD-containing fertilizers was published by Rieder and Michaud (1980). According to Ashworth and Rodgers (1981) ~ 20% of the cost of DCD application is offset by the fertilizer value of the N contained in DCD.

The commercially marketed DCD products, Didin and Alzodin, were developed by Süddeutsche Kalkstickstoffwerke Trostberg Akteingessellschaft, Trostberg, West Germany (hereafter referred to as SKW) in close cooperation with the Institut fur Pflanzenernahrung der TU Munchen at Weihenstephan in West Germany (Amberger, 1981a). Compounds containing urea (Didin) or $(NH_4)_2SO_4$ (Alzodin) are available in granulated and coated form from SKW (SKW 1979a, 1979b), and Chisso Corp. of Japan (Chisso Corp., 1981; Slangen and Kerkhoff, 1984).

Dicyandiamide, abbreviated as DCD, is the most common name for this compound. It is also referred to as cyano-guanidine. The empirical formula is $C_2N_4H_4$. Dicyandiamide has a molecular weight of 84.04 atomic units (AERO, 1964; May, 1979; Weast, 1979). DCD has been thought by most workers to exist as a tautomer with the following structure (Figure 2-2):

```
HN                                  H2N
  \\ H                                 \
   C-N-C≡N          <------>           C=N-C≡N
  /                                    /
H2N                                 H2N

 Tautomer #1                        Tautomer #2
```

Figure 2-2. Tautomers of DCD.

It is generally insoluble in nonpolar solvents and soluble in polar solvents (May, 1979) such as water, (SKW, 1973; Weast, 1979) and liquid anhydrous NH_3 (72 g DCD 100 g^{-1} NH_3 at -33°C) (SKW, 1973; Reitter, 1975; Ashworth and Rodgers, 1981). Its solubility in water is temperature dependent, i.e., 33, 52, and 121 g L^{-1} at 20, 30, and 50°C, respectively (SKW, 1973). It is amphoteric and has an acid dissociation constant (Ka) at 25°C of 6 X 10^{-15}.

Dicyandiamide may exist as an impurity in the now archaic fertilizer $CaCN_2$ (calcium cyanamide, lime nitrogen, or calcium carbamonitrile) (Harger, 1920; Vilsmeier and Amberger, 1978). At one time $CaCN_2$ was a commonly used N

fertilizer in Europe and Japan (May, 1979). Dicyandiamide often appeared as a decomposition product of $CaCN_2$ (Murata, 1939). It makes up approximately 10% of the N in $CaCN_2$ (Amberger, 1981b).

Mechanism of Nitrification Inhibition

General. Nitrification inhibitors affect certain chemosynthetic autotrophic soil bacteria in the Nitrobacteriaceae family by retarding either their growth or their functions. Inhibition of nitrification activity can be caused by interfering with respiration and cytochrome oxidase function, by chelating essential metal ions, by production of acid in the microenvironment, and by liberation of toxic compounds such as mercaptans, sulfoxides, and sulfones (Hauck, 1972).

Lees (1946) observed that chemicals such as Na diethyldithiocarbamate and salicylaldoxime which inhibit copper enzymes, inhibit oxidation of NH_4^+ by *Nitrosomonas*. Quastel (1965) observed that thiourea and allylthiourea inhibit nitrification as well, possibly by combining with metallic cations, such as Cu^{2+}, needed for this process in soil.

It has been proposed that the affinity of the N atom in the structure R-NH-C= for the Cu containing NH_4^+ oxidizing enzyme is primarily involved in inhibition of nitrification (Quastel and Scholefield, 1951). Such a structure occurs in tautomer structure No. 1 of DCD (Figure 2-2). A

closely related structure, with which the former may resonate, i.e. R=N-C=, is contained within the structure of nitrapyrin (Figure 2-1). The other tautomer (No. 2) of DCD contains another related structure, R-N=C-. Both nitrapyrin and DCD inhibit the cytochrome oxidase involved in NH_3 oxidation by Nitrosomonas (Hauck, 1980).

Nitrapyrin. Nitrapyrin inhibits nitrification by inhibiting Nitrosomonas (Goring, 1962a) and has very little effect on Nitrobacter, (Shattuck and Alexander, 1963). Zacherl and Amberger (1984) reported that nitrapyrin was bactericidal rather than bacteriostatic. Shattuck and Alexander (1963) observed that nitrapyrin had no effect on several heterotrophic bacteria and fungi; thus it can be used to distinguish autotrophic from heterotrophic nitrifying organisms.

From their work with pure cultures of Nitrosomonas and Nitrobacter, and others to which nitrapyrin was added, Müller and Hickisch (1979) concluded that the decrease in the number of microorganisms is small and cannot be the only explanation for the inhibition of the nitrification process over a relatively long period. Hooper and Terry (1973) concluded that the effect of nitrapyrin was irreversible because they found that NO_2^--N or NO_3^--N accumulation did not recommence in cell-free extracts after treatments with nitrapyrin had finished.

Goring (1962a) studied the effect of reinfestation (reinoculation) by nitrifying bacteria contained in small amounts of fresh soil, on the control of nitrification by nitrapyrin. Nitrification proceeded more rapidly in reinfested than in uninfested soil. He presumed that nitrapyrin destroys the majority of the nitrifying organisms and is then decomposed to nonlethal concentrations. The rate of recovery of nitrification thus depended on the recovery of the surviving nitrifying organisms and was, therefore, enhanced by repeated reinfestation.

Rodgers et al. (1980) found that recovery of nitrifying bacteria took approximately 40 days after a 1 mg L^{-1} addition of nitrapyrin to aqueous suspensions of different soils to which 200 mg NH_4^+-N L^{-1} was added. Even after prolonged incubation with nitrapyrin, no evidence was obtained for the development of nitrapyrin resistant nitrifying organisms. Research with different strains of *Nitrosomonas* (Belser and Schmidt, 1981; Laskowski and Bidlack, 1977) showed substantial differences in sensitivity among strains, to nitrapyrin.

Dicyandiamide. Dicyandiamide inhibits nitrification by interfering with the metabolism of *Nitrosomonas* (Verona and Gherarducci, 1980; Amberger, 1981a), specifically by inhibiting the oxidative phosphorylation (Amberger, 1984) of the Cu containing cytochrome oxidase enzyme which oxidizes NH_4^+ (Hauck, 1980). Amberger (1981b) proposed that there is

a temporary decoupling of respiration and energy transfer in Nitrosomonas due to a reaction of the C≡N group of DCD with sulfhydrile groups and heavy metals of cytochrome oxidase. He based this proposal on the results of his earlier work (Amberger, 1978) with cyanamide and related products.

Dicyandiamide is a bacteriostat, not a bactericide (Zacherl and Amberger, 1984). The microbial effects of DCD are selective for Nitrosomonas, with no effect on the fungi, cellulose-decomposing bacteria, ammonifying and denitrifying bacteria, Azotobacter (Verona and Gherarducci, 1980), or Rhizobium sp. (Neglia and Verona, 1976) that were tested.

Verona and Gherarducci (1980) found that several days after application of DCD, the numbers of Nitrosomonas in soil eventually decreased. After the DCD had decomposed, the original numbers of Nitrosomonas reappeared in the soil. Solansky (1981) commented that this reduction of numbers must represent a decrease in the bacteria's rate of multiplication as a result of their starvation due to a lack of metabolic substrate.

Inhibitor Concentration Effects and Longevity

Nitrapyrin. Reports of the duration of nitrapyrin's nitrification inhibiting effect have been various: 15 days for complete inhibition and 49 days for partial inhibition (Hendrickson et al., 1978), 59 days (Westermann et al., 1981), 91 to 100 days (McCormick et al., 1983), 112 days

(Terry et al., 1981), 148 days (Liu et al., 1984), and 280 days (Janssen, 1969).

Goring (1962a) found that the minimum active concentrations of nitrapyrin for a six-week incubation period in 87 soils (with 200 mg kg^{-1} NH_4^+-N) were principally in the 0.2 to 2.0 mg kg^{-1} range, but a few were as high as 20 mg kg^{-1} and several were as low as 0.05 mg kg^{-1}. A number of workers have found that under laboratory and field conditions, nitrapyrin inhibited nitrification of NH_4^+ and amide fertilizers at rates varying from 0.2 to 2.0% of applied N (Goring, 1962a, 1962b; McBeath, 1962; Turner et al., 1962; Gasser and Penny, 1964; Nielson and Cunningham, 1964; Sabey, 1968).

McCormick et al. (1984) recommended that nitrapyrin should be applied at a rate of 0.8 to 0.9 kg ha^{-1} with a banded fertilizer application to give effective control of nitrification. Goring and Scott (1976) reported that the rates of nitrapyrin application advised by Dow Chemical Company were 4.5 to 6.75 L ha^{-1} of N-Serve 24 or 24E for potatoes before or after planting. These recommended rates were based on fertilizer application in bands or rows (Goring and Scott, 1976).

<u>Dicyandiamide</u>. Bazilevich (1968) grew corn in potted soil and found that 35 days after DCD application, the inhibiting effect of DCD on the rhizosphere microflora was still observed, while after 50 days the number of

microorganisms increased but remained less than control populations; after 85 days populations were the same as the control.

Bazilevich and Kabanova (1973) found that 6.8 kg DCD ha^{-1} inhibited nitrification of applied $(NH_4)_2SO_4$-N for 1 to 1.5 months. Smirnov (1978) observed that 10 to 15% of the amount of applied N as DCD-N was needed to inhibit the nitrification of fertilizer derived and native NH_4^+-N for a period of 1.5 to 2 months.

Amberger and Guster (1978) found that DCD at 5 to 10% of the applied N was sufficient to inhibit nitrification in a pot culture with sandy loam (pH 6.1) over at least 6 weeks. Without any inhibitor, Amberger and Vilsmeier (1979c) found that 50% of total N and 100% of NH_4^+-N, applied to soil in the laboratory as liquid manure was nitrified within 20 to 40 days at temperatures of 8 to 20°C. Addition of DCD at a rate of 10 mg DCD kg^{-1} of liquid manure resulted in intensive inhibition of nitrification for 20 to 60 days depending on environmental conditions such as leaching rainfall and soil temperature. Increased DCD rates lengthened these times. Reddy (1964a), in incubation studies with DCD and $(NH_4)_2SO_4$ in Georgia coastal plain soils, found that with Cecil sandy loam (Paleudult) and Lakeland sand (Quartzipsamment), 25 mg kg^{-1} DCD inhibited nitrification for up to 90 days. Some inhibition was still

occurring after 150 days in the Lakeland soil (Reddy, 1964a).

In a laboratory incubation study with a Mulat sand (Typic Ochraquult) from the Horticulture Unit near Gainesville, Florida, Mohamad (1985) found that the duration of DCD effectiveness was directly related to DCD concentration in the soil. With 5 and 10 mg DCD kg^{-1} soil, 100 mg of added NH_4^+-N kg^{-1} soil was subject to considerable nitrification within two weeks. With 25 mg DCD kg^{-1} soil, however, significant nitrification did not occur for eight weeks and some inhibition of nitrification continued for at least twelve weeks. He found that the effectiveness of DCD added to soil at the rate of 10 mg kg^{-1} was not affected by NH_4^+-N concentrations in the soil within the range of 0 to 120 mg NH_4^+-N kg^{-1} soil.

In a field study with the same Ochraquult, Mohamad (1985) found that the duration of inhibition varied from year to year and varied with N rate and DCD rate. In one year with 22.4 kg ha^{-1} DCD and 202 kg ha^{-1} urea-N, DCD increased soil NH_4^+-N concentration for eight weeks. With 11.2 kg ha^{-1} DCD, however, NH_4^+-N concentrations were only increased for four weeks. With these DCD and N rates, NO_3^--N concentration in the soil was reduced for four weeks. In a second year, 11.2 kg ha^{-1} DCD had little effect on soil NH_4^+-N or NO_3^--N concentrations while 22.4 kg ha^{-1} DCD

increased soil NH_4^+-N concentration for six weeks and decreased soil NO_3^--N concentration for four weeks.

Vilsmeier and Amberger (1978) found that DCD as 10% of applied N in $(NH_4)_2SO_4$ and urea strongly inhibited nitrification for an average of 60 days. Randal and Malzer (1981) found that DCD inhibited nitrification of NH_4^+ from $(NH_4)_2SO_4$ and urea for a maximum of 9 weeks. In the laboratory, Rathstack (1978) added urea and large concentrations of DCD to soil under environmentally controlled conditions. He found that as DCD-N (as a percent of applied N) increased from 10 to 20 to 30%, nitrification inhibition continued for 26, 32, and 45 days respectively. In a field study, Touchton (1981b), however, found that 5% DCD-N as a percentage of total N was as effective in inhibiting nitrification as 10 and 15% rates.

These and other reports indicate that DCD is effective at inhibiting nitrification for a minimum of 20 days, more often for 40 to 60 days, and occasionally for as long as 90 days. These values are sometimes but not always a function of DCD concentration in the soil or N fertilizer. The duration of inhibiting effects and the effective concentration vary with soil type and environmental conditions. Since effective inhibition is likely to taper off gradually, it is not possible to determine exactly the duration of effectiveness.

Inhibitor Losses

Volatilization of nitrapyrin. Nitrapyrin has a relatively low vapor pressure of 0.373 N m^{-2} (at 23°C) (Goring, 1962b). This is the reason that application of nitrapyrin in spots or bands, instead of broadcasting, is preferred (Turner et al., 1962). According to Hendrickson et al. (1978), nitrapyrin is more likely to be lost to volatilization when sidedressed, even though covered with soil, than when applied at planting. Nitrapyrin volatilizes rapidly when unincorporated into the soil, resulting in losses of up to 80% (Briggs, 1975) and thus is much more effective as a nitrification inhibitor when incorporated (Briggs, 1975; Gasser and Penny, 1964). This volatility results in gaseous diffusion of nitrapyrin through air-filled pores in the soil (Goring, 1962b) and can be aggravated by wind at the soil surface (McCall and Swann, 1978). Higher soil temperatures accelerate the rate of diffusion of nitrapyrin in soils (Hendrickson et al., 1978).

Because of its volatility, low water solubility, and sorption by soil organic matter, nitrapyrin has very little tendency to leach downward in the soil (Mullison and Norris, 1979). When NH_4^+-N fertilizer is applied to soil with nitrapyrin, much of the NH_4^+-N can leach down below the zone of soil containing nitrapyrin, thus rendering the inhibitor ineffective (Hendrickson et al, 1978; Rudert and Locascio, 1979b).

Decomposition (hydrolysis) of nitrapyrin. The principal decomposition residue of nitrapyrin in plants and soils is 6-chloro-picolinic acid, formed by hydrolysis of the trichloromethyl group (Briggs, 1975; Herlihy and Quirke, 1975; Hendrickson and Keeney, 1979; Redemann et al., 1964, 1965). Hydrolysis of nitrapyrin is enhanced in moisture saturated soils (Hendrickson and Keeney, 1979; Laskowski et al., 1974). As soil temperature increases, the rate of nitrapyrin hydrolysis increases exponentially (Redemann et al., 1964; Hendrickson and Keeney, 1979). Hendrickson and Keeney (1979) found that the rate of nitrapyrin hydrolysis was not affected by pH in the 2.7 to 11.9 range. Touchton et al. (1979b) found, on the other hand, that the rate of nitrapyrin disappearance increased with increasing soil pH in 2 of 3 soils tested.

Redemann et al. (1964) found that the amount of applied nitrapyrin remaining in the soil was an exponential function of time and observed a half life (residence half time) for nitrapyrin in four soils, from 4 to 22 days at 20°C. Herlihy and Quirke (1975) observed nitrapyrin half lives ranging from 9 to 16 days at 20°C and from 43 to 77 days at 10°C.

Decomposition of DCD. That DCD which is retained in the soil eventually breaks down into NH_4^+-N and NO_3^--N and carbon compounds, presumably by the action of soil microorganisms (Rathstack, 1978). Rieder and Michaud (1980)

reported that rapid mineralization of DCD-N to NH_4^+-N and NO_3^--N in three soils began after 28 days and was complete after approximately 70 days. Garita (1981) applied DCD to soil in a banana plantation in Costa Rica. When the DCD was in an $(NH_4)_2SO_4$ formulation (Alzodin), none was detectable in soil extracts after 46 days. When it was applied in a urea formulation (Didin), none was detectable after 59 days. Graetz et al. (1981) applied DCD to soil under sweet corn (<u>Zea</u> <u>mays</u> L. var. <u>saccharata</u> (Sturt.) Bailey.) in Northeast Florida and found detectable DCD in soil extracts 77 days after application. Kappan (1907) concluded that DCD decomposed more slowly in infertile soils than in fertile soils.

In an incubation study, Vilsmeier (1980) was able to identify the breakdown products of DCD in soil. The sequence of reactions was shown to be

$$\text{DCD} \dashrightarrow \text{guanylurea} \dashrightarrow \text{guanidine} \dashrightarrow NH_4^+ \qquad [2]$$

As temperature increased, the rate of breakdown increased, particularly for the DCD to guanylurea step. At very high temperatures (70°C), guanidine accumulated.

Whereas the rate of decomposition of DCD in soil depends on temperature and quantity of DCD applied, soil moisture content has been said to play only a minor part (Vilsmeier, 1980, 1981; Amberger and Vilsmeier, 1979a, 1979b). Murata (1939) observed that DCD was ammonified

under waterlogged conditions. A low value for P_{O2} (Eh less than 250 mv at pH 7) and the presence of FeO or actively decomposing organic matter was favorable for DCD decomposition (Murata, 1939). Bazilevich (1968) found that DCD was decomposed much faster in plant-bearing than in fallow or untilled soil. Thus, he concluded that plant root exudates were used as nutrients or carbon sources by the microorganisms which break down DCD, with DCD acting as an N source for these microorganisms. Reddy and Datta (1965) observed that the nitrification inhibiting effect of DCD was partially counteracted by the addition of organic matter. In the presence of added organic matter, decomposition of DCD was more rapid. They attributed this rate effect to the high exchange capacity and absorbing power of the organic matter. Reddy (1964a) claimed that DCD decomposed faster in a sandy loam soil with a relatively high organic matter content than in a coarse textured sandy soil with a low organic matter content.

Leaching of DCD. If leaching of NO_3^--N is a reason for using nitrification inhibitors, then leaching of the inhibitors should also be of much interest. The volatility of nitrapyrin can cause NH_4^+-N to move below the zone of maximum nitrapyrin concentration in the soil (Rudert and Locascio, 1979b). DCD, on the other hand, does not volatilize but is subject to leaching (Amberger and Guster, 1979; Bock et al., 1981; Sampei and Fukushima, 1973). If it

leaches more rapidly than NH_4^+-N, then its effectiveness will be compromised (Bock et al., 1981).

Amberger and Guster (1979) observed that as much as 15% of the DCD applied with liquid cattle manure to potted soil in the greenhouse was leached by 56 mm of simulated percolation. More DCD was leached from fallow potted soil than when growing plants were present.

Bock et al. (1981) studied the movement of DCD and various sources of fertilizer N through soil columns. While NH_4^+ is held against leaching to some extent by the cation exchange capacity, even in sandy soils, the tautomers of DCD carry little charge; thus DCD can separate from the NH_4^+ when the two are applied together. Under conditions of mass flow, this separation was observed by Bock et al. (1981). This did not occur with urea, however, since DCD and urea moved with the soil solution at about the same rate. This is not surprising since urea also is uncharged.

Retention of DCD in six soils (belonging to several soil orders) studied by Bock et al. (1981) generally increased with increasing soil organic matter content and cation exchange capacity (CEC). DCD is only weakly sorbed by soil organic matter (Vilsmeier, 1979), but even weak sorption could be significant. Bock et al. (1981) observed no relationship between soil pH or presence of free calcium carbonate and DCD retention. They found that a simulated 5

cm rainfall moved most of a surface applied DCD solution below the 5 cm depth in all the soils studied.

Effects of Inhibitors on Other N Transformations

Volatilization of NH_3. Rodgers (1983) reported that the use of DCD increased the amount of NH_3 lost by volatilization 20 to 60% compared to soil amended with urea only. He concluded that the beneficial effects of DCD may be counteracted by increased loss of NH_3 by volatilization. Apparently no other research has been reported on the effects of nitrification inhibitors on NH_3 volatilization.

Volatilization of NH_3 may have been the reason for some of Graetz et al.'s (1981) field results with vegetables. They found that with plastic mulched tomato (*Lycopersicon esculentum* Mill.) fruit yield was increased with addition of DCD to NH_4NO_3 and to urea. With unmulched bell peppers (*Capsicum frutescens* var. grossum (L.) Bailey), DCD increased fruit yield when NH_4NO_3 was used but decreased yield when urea was used.

N mineralization. Kreitinger et al. (1985) found that nitrapyrin stimulated N mineralization rates by 77% in soil suspensions not receiving NH_4^+-N and by 40% in NH_4^+-N supplemented suspensions. The reason for this anomalous observation was not apparent. The fixation of CO_2 was not increased by the addition of NH_4^+-N to suspensions of leached soil. However, nitrapyrin inhibited CO_2 fixation in both NH_4^+-amended and unamended suspensions.

In a field study with ^{15}N, Norman et al. (1989) found that DCD increased mineralization of organic N in rice paddy soil and increased plant uptake of native soil N as opposed to fertilizer N. In a field lysimeter study with ^{15}N applied to corn (Zea mays L.), Walters and Malzer (1990b) obtained similar results with nitrapyrin. In a laboratory incubation study, however, Mohamad (1985) found that DCD did not affect mineralization of soil organic N in a sandy Florida Ochraquult.

Denitrification. Nitrification inhibitors indirectly inhibit denitrification because of their inhibition of nitrification (Mitsui et al., 1964). Evidence for this indirect inhibition has been provided for flooded soils (Prasad and Lakhdive, 1969; Rajale and Prasad, 1970; Sampei and Fukushima, 1973) and for nonflooded soils (Nishihara, 1962; Smirnov et al., 1977; Liu et al., 1984; Cribbs and Mills, 1979; McElhannon and Mills, 1981; Kostov, 1977; Vilsmeier, 1981). Others have observed that inhibitors such as DCD did not affect denitrification (Mitsui et al., 1962; Simpson et al., 1985). Since nitrification is inhibited, less NO_3^- (the substrate for denitrification) is formed from NH_4^+ (Meyer, 1981; Vilsmeier, 1981). This indirect effect on denitrification is of practical importance, especially where crops such as rice (Oriza sativa L.) are grown in flooded soils.

N immobilization. Hauck (1972) observed that nitrification can result in a reduction of N immobilization and NH_3 fixation. It follows, therefore, that inhibition of nitrification could increase N immobilization and fixation. When Chancy and Kamprath (1982) applied nitrapyrin to corn, they observed that nitrapyrin resulted in more of the total inorganic N in the 0 to 15 cm depth being in the NH_4^+ form. However, this did not significantly increase the total inorganic N concentration at any depth. They could not explain this discrepancy; they did not consider the possibility of increased immobilization.

Terry et al. (1981) reported no effect of nitrapyrin on immobilization of NH_4^+-N added with synthetic sewage sludge to a silt loam (Aeric Ochraqualf) soil. In a laboratory study under controlled conditions, Mohamad (1985) did not observe any effect of DCD on fertilizer N immobilization. In another laboratory study, however, Osiname et al. (1983) did observe an increase in immobilization of fertilizer N with nitrification inhibitors.

Until recently, most of the research investigating the effects of nitrification inhibitors on the immobilization of fertilizer N has been done by Smirnov's group in the Soviet Union. Smirnov et al. (1968) amended ^{15}N labeled $(NH_4)_2SO_4$ and urea with DCD and found that although N losses were markedly lowered by DCD application, more of the fertilizer N was immobilized in organic forms in the soil as a result

of DCD application. Smirnov (1968) applied ^{15}N labeled NH_4^+-N fertilizers amended with DCD, to barley and oats. He found that DCD application increased utilization of fertilizer N by the crops somewhat, almost halved losses of N, and increased transformation of fertilizer N into organic N. Smirnov et al. (1972a, 1972b) found that DCD application increased the immobilization of fertilizer N under corn, but not under oats (<u>Avena sativa</u> L). In another study, Smirnov et al. (1973) applied DCD as 0.5% of the fertilizer weight with $(NH_4)_2SO_4$ and urea at the rate of 120 mg N kg^{-1} soil. They found that N losses were reduced by 23 to 25% with $(NH_4)_2SO_4$ and by 12 to 14% with urea, while immobilization of fertilizer N was increased by DCD application.

Juma and Paul (1983) found that the nitrification inhibitor 4-amino-1,2,4-triazole (ATC) increased the recovery in Canadian topsoil of ^{15}N supplied as labelled urea or aqueous NH_3, by 41 to 57% on the average, without increasing ^{15}N uptake (37%) by wheat. Soil treated with ATC contained nearly twice as much ^{15}N in the biomass as untreated soil. Ashworth et al. (1984) found that similar increases in non-extractable soil ^{15}N were measured after incubating soils from Alberta, Canada, in the laboratory with labeled $(NH_4)_2SO_4$ and the inhibitor etridiazol. Norman et al. (1989) found that DCD increased immobilization of fertilizer N applied to paddy soil in Arkansas. Walters and Malzer (1990a, 1990b) found that in the first year of their study,

nitrapyrin increased immobilization of incorporated urea-N and decreased plant recovery of fertilizer derived N (FDN) in a Typic Hapludoll in Minnesota. This led to an increase the following year in mineralization, plant uptake, and leaching of residual FDN.

N Leaching and Inhibitor Effects

Potato production in many regions of the world is concentrated in areas of sandy soils where irrigation is common (Bundy et al., 1986). Irrigation of the potato crop is considered essential on such sands and lighter soils (Curwen et al., 1982). Potato grown on these soils is relatively shallow-rooted (Lesczynski and Tanner, 1986) and requires frequent irrigation (Curwen and Massie, 1984) and high N fertilizer rates (Kelling et al., 1984) to maximize tuber yield and quality. In studies with Russet Burbank potato on a loamy sand, more than 90% of the root length was in the upper 30 cm of the soil profile (Lesczynski and Tanner, 1976; Tanner et al., 1982); thus fertilizer N leached below 30 cm is not likely to be recovered by the crop (Bundy et al., 1986).

In such an environment, the potential for loss of fertilizer N by means of leaching of NO_3^--N is high (Bundy et al., 1986). Some of these soils have such low CEC and water holding capacities that appreciable leaching of NH_4^+-N can occur as well. The tendency of NH_4^+-N to leach would be accentuated if fertilizer N persists in the NH_4^+ form for an

extended period of time, or if the concentrations of soluble salts in the soil are high (Hendrickson et al., 1978).

It is not unusual for potato growers to apply water frequently and in amounts in excess of actual evapotranspirational losses. This practice can be wasteful and in some cases reduce tuber yields by leaching fertilizer N beyond the root zone, and by creating anaerobic conditions in poorly drained soils (Wolfe et al., 1983).

Nonuniform water infiltration under potato plant canopies can promote N leaching losses and decreased crop recovery of fertilizer N (Lesczynski and Tanner, 1976; Saffinga et al., 1976; 1977; Tanner et al., 1982). In sandy Entisols of central Wisconsin, only 2.5 cm of applied water resulted in a 15 to 20 cm downward movement of added NO_3^--N (Endelman et al., 1974). In Long Island, NY, rates of N fertilizer in excess of potato crop requirements resulted in NO_3^--N enrichment of the groundwater (Meisinger, 1976).

It can be difficult to accurately determine NO_3^--N movement in field soils. The presence of water flow channels in the soil can result in rapid movement of applied N fertilizer not only to regions below the rooting zone, but below the zone of biodegradation as well. As a result, much of the downward moving NO_3^--N tends to avoid contact with installed sampling devices such as porous cup extractors (Simpson and Cunningham, 1982). Peak water and leachate flow periods may be missed entirely because of this

channelization (Rourke, 1985). This makes accurate measurements of movement of inorganic N difficult in a soil planted to potato (Simpson and Cunningham, 1982).

Under overhead irrigation, soil NO_3^--N and other soluble salts move downward and decrease in concentration as the crop growing season progresses. Elkashif et al. (1983) observed this to be the case in Northeast Florida at the University of Florida Horticulture Unit at Gainesville, Florida. At the Agricultural Research and Education Center (AREC) at Hastings, Florida, potato was grown with subsurface irrigation and they observed that soil soluble salts increased as the season progressed, due to low rainfall and upward movement of soluble salts as water evaporated during dry periods. These reports indicate that potato fields present special challenges for the accurate measurement of N leaching.

Nitrification inhibitors have been shown to reduce losses of N accompanying nitrification vis. leaching and denitrification under situations where these losses are high (Sahrawat et al., 1977), thus reducing NO_3^--N pollution of ground and surface waters (Huber et al., 1969; Norris, 1972). Touchton et al. (1979a) reported that nitrapyrin prevented NO_3^--N from accumulating below the 15 cm depth in a somewhat poorly drained Typic Hapludoll in Illinois. In percolation studies, Nishihara and Tsuneyoshi (1968) found

that the amount of N in the percolate (leachate) was greatly reduced by amendment of urea with nitrapyrin.

Soubies et al. (1962) applied DCD in the fall at a rate of 5.5 to 24% of fertilizer N, which reduced leaching losses of N over the winter by as much as 67%. Kiangsi (1976) found that DCD and other inhibitors prevented more than 20% of the N losses caused by leaching of soil NO_3^--N. Scheffer et al. (1984) found that DCD reduced leaching of mineral fertilizer N applied to sandy soils by an average of 28%. When DCD was applied with liquid manure, however, leaching was reduced with fall application but not with spring application. Kuntze and Scheffer (1981) found that DCD reduced NO_3^--N leaching into subsoil drainage water by 20%. Kick and Poletschny (1981) found that during the German winter, DCD resulted in reduction of N leaching by 67 to 80%.

Timmons (1984) found that nitrapyrin reduced NO_3^--N leaching losses by 30 to 51 kg ha^{-1} in a column study. Using ^{15}N and field lysimeters planted to corn on a sandy loam (Typic Hapludoll) in Minnesota for three years, he found that the average quantity of NO_3^--N leached was 12 kg ha^{-1} (7%) less when urea was applied with nitrapyrin than when urea was applied alone. His results were very inconsistent because of variability in amounts of leaching rainfall, plant uptake of fertilizer N, and other factors.

In a similar three year study with lysimeters on the same soil, Walters and Malzer (1990a, 1990b) found that the maximum rate of NO_3^--N leaching loss was delayed 25 to 50 days when nitrapyrin was applied with 180 kg ha^{-1} urea-N. Although nitrapyrin reduced soil water percolation, the quantity of N leached was not reduced over the three year period. They found that the effects of nitrapyrin on NO_3^--N leaching were confounded by the long term effects of nitrapyrin on N immobilization and mineralization. This paper was the first to describe the long term effects of a nitrification inhibitor on most relevant portions of the soil N cycle. An important factors that was not measured, however, was inhibitor effects on volatilization of NH_3. In the first year, nitrapyrin resulted in a decrease in NO_3^--N leaching due to an increase in immobilization of fertilizer N. In subsequent years, this immobilized (residual) fertilizer N was mineralized, increasing leaching of NO_3^--N.

Plant N uptake and N rate influenced this set of relationships. While plant recovery of FDN in the year of application was decreased by nitrapyrin, greater uptake of residual FDN in subsequent years tended to equalize the total amount of FDN recovered in plant material by the third year of their study. In the previously unfertilized soil which was used in their study, they found that N leaching losses increased in each successive year. This reflected mineralization and leaching of residual immobilized N from

the previous year's application. They observed that a two-fold increase in N application rate resulted in a 3.4-fold increase in N leached over three years. The relative difference in N leaching levels with two N rates increased with each succeeding year. In part this was because less of net fertilizer N remained immobilized after one year with a 180 kg ha^{-1} N rate than with a 90 kg ha^{-1} N rate (Walters and Malzer, 1990a, 1990b).

These reports indicate that in the field, inhibitors can sometimes reduce NO_3^--N leaching, at least temporarily, by as much as 70 to 80% but more often by 5 to 30%. The only long-term well-controlled field experiments reported in the literature showed an average reduction in leaching of NO_3^--N, of only 7% in one case (Timmons, 1984) and no reduction at all in another (Walters and Malzer, 1990b).

Crop Response to Inhibitors

According to Hauck (1972), decreased N losses and increased crop yields resulting from the use of nitrification inhibitors are readily demonstrated in laboratory and greenhouse experiments. It is far less easy to demonstrate the value of nitrification inhibitors in field soils since field experiments usually are more insensitive than laboratory and greenhouse tests, and small differences in efficiency of N use are difficult to measure accurately. Also, in a single season, beneficial effects of controlling nitrification may not be obvious. For example, rapid

nitrification may not precede conditions conducive to NO_3^--N loss by denitrification or leaching. Therefore as discussed by Hauck (1972), reports appear in the literature that nitrification was inhibited by a chemical in the laboratory but that this inhibition was not reflected in increased yield or N uptake or that anomalous results were obtained (Ashworth et al., 1980, 1984; Colliver, 1980; Maddux et al., 1985; Meisinger et al., 1980; Touchton, 1981; Welch, 1979).

A substantial amount of literature exists reporting on the effects of nitrapyrin and DCD on the crop yields, yield components, and N contents of corn, wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), potato, pasture and fodder grasses, spinach (*Spinacia oleracea* L.), and to a lesser extent, on sorghum (*Sorghum vulgare* Pers.), rye (*Secale cereale* L.), oat, barley (*Hordeum vulgare* L.), cotton (*Gossypium hirsutum* L.), sugar beet (*Beta vulgaris* L. (Mangels)), turf grasses, and various vegetables. A number of greenhouse studies have indicated that DCD can increase yield and/or N uptake by some crops. The effects of DCD on crop yields in field studies have been mixed. Dicyandiamide appears to have given better results in Europe than in the USA. The majority of the work reported on nitrapyrin has been conducted in the USA with lesser amounts in the Commonwealth countries and the European community. The most extensive research with DCD has been conducted in West

Germany, the USSR, and the USA, and to a lesser extent in Japan, India, The Netherlands, France, England, and Poland.

In a number of field studies that were conducted for two or more years, the effects of nitrification inhibitors on crops varied considerably from year to year with seed cotton (Reeves et al., 1988), winter barley (Guster, 1981), and other crops, especially when the inhibitor was applied in the summer (Guster, 1981). The effectiveness of inhibitors such as DCD has also varied from one soil to another in the same year (Nishihara, 1962).

In the USA, some researchers observed no corn yield increase when nitrapyrin was applied (Touchton et al., 1979; Boswell, 1977, Robertson et al., 1982). In other cases, yield increases occurred only at low N rates (Touchton et al., 1979a; McCormick et al., 1984, Walters and Malzer, 1990a), only with fall N application (Touchton et al., 1979a; McCormick et al., 1984), or only when temperatures were low and rainfall was excessive during the early growth period (Touchton and Boswell, 1980). In some cases, nitrapyrin has resulted in decreased corn yields (Robertson et al., 1982; Touchton et al., 1979a; Walters and Malzer, 1990a). Other workers have observed more favorable results (Tsai et al., 1978; Malzer et al., 1979).

Summarizing the studies on nitrapyrin application to corn in Kansas (Dept. of Agron., Kansas State U., 1976, 1977, 1978), those irrigated corn sites where yield

increases due to nitrapyrin occurred, were on sandy soil. Smirnov (1978) observed that in the USSR, crop yield increases resulting from DCD application, occurred most often in the humid regions of the country and under irrigation. Of all the crops tested in the USSR, increased yields due to DCD application were most common with cotton and rice (Smirnov, 1978).

In the USA, researchers observed corn yield decreases (Reddy, 1964b) or no increase when DCD was applied (Graetz et al., 1981; Randal and Malzer, 1981). When DCD application did not increase crop yields, this has been attributed to the lack of substantial leaching rainfall (Graetz et al., 1981; Touchton, 1981; Robertson et al., 1982; Mohamad, 1985).

Yield was not increased by nitrapyrin application to tomato (Jaworski and Morton, 1967), sweet corn (Zea mays var. sacharata Bailey) (Rudert and Locascio, 1979a), radish (Raphanus sativus L.) (Sander and Barker, 1978), kale (Brassica oleracea L. var. acephala D.C. (Borecole)) (Spratt and Gasser, 1970), cabbage (Brassica oleracea convar. capitata (L.)) (Gysi and Stroll, 1980), Chinese cabbage (Brassica pekinensis (Lour.) Rupr.) (Roorda van Eysinga and Meijs, 1980), mustard (Brassica campestris L.) (Jung and Dressel, 1978), endive (Cichorium endivia L.) (Roorda van Eysinga and Meijs, 1981), and lettuce (Lactuca sativa L.) (Moore, 1973). In other cases, nitrapyrin increased sweet

corn (Swezey and Turner, 1962) and tomato (*Lycopersicon esculentum* Mill.) yields (Graetz et al., 1981). In one study, nitrapyrin only increased lettuce yields when irrigation was frequent (Welch et al., 1979).

In several studies, DCD has had no effect on the yields of sweet corn (Mohamad, 1985), lettuce (Roorda van Eysinga et al., 1980d), endive (*Cichorium Endivia* L.) (Roorda van Eysinga and Meijs, 1981), Chinese cabbage (Roorda van Eysinga and Meijs, 1980), or onion (*Allium cepa* L.) (Rotini and Guerrucci, 1961).

As with other crops, potato yield responses to nitrapyrin have varied. In some cases nitrapyrin application has decreased potato yields even though it was effective in inhibiting nitrification (Hendrickson et al., 1978; Vendrell et al., 1981). In other cases it has had no effect (Potter et al., 1971; Roberts, 1979). In yet others, it has increased yields (Roberts, 1979). The effects of nitrapyrin on potato tuber quality factors have likewise been sometimes negative (Hendrickson et al., 1978) and sometimes positive (Potter et al., 1971). In some cases nitrapyrin has been found to reduce incidence of potato scab (*Streptomyces scabies*) (Huber and Watson, 1970; Potter et al., 1971).

Lack of potato yield response to nitrification inhibitor application was observed by Schmitt (1938), Amberger (1981b), and Munzert (1984). Potato yield increases, mostly in Europe, were observed by Schmitt (1937), Rieder (1981),

Wolkowski et al. (1986), and Munzert (1984). In some cases, these increases only occurred at low N rates (Smirnov et al., 1976a).

In Germany, Munzert (1984) found that when potato yields were increased by DCD application, more oversized tubers were produced. Wolkowski et al. (1986) commented that early research by others had shown that use of nitrification inhibitors on potatoes with completely NH_4^+-N sources, while sometimes resulting in improved N efficiency, also resulted in decreases in tuber grade and yield. They attributed this to the potato's aversion to exclusive NH_4^+-N nutrition. In their own study, they found that DCD increased yield and fertilizer N use efficiency but in some cases depressed tuber grade.

Why nitrification inhibitors often do not increase crop yields. Several studies have found that nitrification inhibitors increased crop yields much more, or only, at the lowest of several N rates (Huber et al., 1981; Liu et al., 1984; Touchton, 1981; Bazilevich and Kabanova, 1973; Krischenko et al., 1972; Makarov and Gerashchenko, 1976; Frye et al., 1981; Malzer et al., 1979; McCormick et al., 1984; Amberger, 1981b; Smirnov et al., 1972a, 1973, 1976a, 1976b). Ashworth (1986) considered the tendency of nitrification inhibitors to increase immobilization of applied N as a possible explanation for the inconsistent and sometimes

slightly negative effects of inhibitors on crop yield (Ashworth et al., 1980, 1984; Meisinger et al., 1980).

McCormick et al. (1984) concluded that when nitrification is inhibited but no yield responses occur, either (1) the soil already contains high concentrations of plant available N and the addition of N fertilizer does not increase yield, (2) little or no N losses occur following fertilizer application, or (3) N rates used are far in excess of those required for maximum yield.

Blackmer (1986) presented a hypothesis that does much to explain why crop yields are often not increased by nitrification inhibitors, as well as split N fertilizer applications, urease inhibitors, and slow release N sources. He proposed that the lack of response to inhibitors, etc., could be the result of several causes including (1) significant losses of N did not occur in the absence of the treatment; (2) the treatment was not effective at preventing losses; (3) N availability was not a factor limiting crop growth, even after significant losses occurred; (4) unexpected effects of the treatments masked the intended effects; and (5) the experimental method lacked sufficient sensitivity to detect significant yield responses that occurred.

Treatments conserving fertilizer N should be expected to cause statistically significant increases in crop yields only when a favorable interaction among the following

conditions is attained: (1) experimental methods provide a high degree of precision, (2) the treatment saves a substantial portion of the fertilizer N applied, (3) fertilizer N is applied at relatively low rates, and (4) studies are conducted on soils having small amounts of soil derived available N (Blackmer, 1986).

Effective nitrification inhibitors sometimes result in excess NH_4^+-N availability or NO_3^--N deficiency in NH_4^+-N sensitive or NO_3^--N requiring species. These two problems can occur together and can be hard to separate. Imbalances of NH_4^+/NO_3^- in the nutrition of the crop may induce or be accentuated by K deficiency (Barker et al., 1967) and/or Cl toxicity. Inhibition of nitrification may in such cases lead to yield depressions with crops that are not able to assimilate relatively high amounts of NH_4^+-N (Dibb and Welch, 1976; Kapusta and Varsa, 1972). In some cases an increase in the NH_4^+/NO_3^- ratio can cause a redistribution of N inside the plant, sometimes resulting in changes in crop protein content, but not necessarily in crop yield (El Wali et al., 1979; Sommer and Rossig, 1978; Touchton et al., 1979a; Warren et al., 1980).

Nitrogen Nutrition of Potato and Other Plants

General

The quantity and form of N available to the potato crop have substantial effects on the internal physiology of

the plant, tuber initiation, vine growth, tuber yield and specific gravity, proportion of cull tubers, leaf N concentrations, disease susceptibility, N leaching, and N fertilizer use efficiency. Nitrogen has been reported to play a major role in the production and maintenance of optimum plant canopy for continuous tuber bulking through long growing seasons (Bremner and Taha, 1966; Bremner and Radley, 1966; Moorby, 1978). When N fertilizer rates are high to excessive, the proportion of the total tuber crop made up by culls, especially misshapen or oversized culls, has been found to increase (Bundy et al., 1986; Chamberland and Scott, 1968; Murphy and Goven, 1975; Terman et al., 1951; Westermann and Kleinkopf, 1985).

Nitrogen Source

It has been recognized for quite some time (Maze, 1900; Muntz, 1893) that most plants may utilize either NH_4^+ or NO_3^- salts as N sources. Different plant species, however, differ in their uptake and assimilation of NH_4^+-N and NO_3^--N (Barker and Mills, 1980). The uptake and use of NH_4^+-N v NO_3^--N by plants are related not only to the form of N but also to the associated ion, the concentration of other nutrients present, and plant factors such as age and nitrate reductase activity (Hauck, 1972). Hewitt et al. (1976) and Street and Sheat (1958) concluded that NO_3^--N is usually superior to NH_4^+-N for plant growth, but the two sources may

vary with species, environmental conditions, soil conditions such as pH, and other factors.

According to Nightingale (1948), NH_4^+-N nutrition differs from NO_3^--N nutrition in three main ways; (a) the demand for O_2 to the roots is increased with NH_4^+-N nutrition, (b) competition for absorption of cations other than NH_4^+ may be detrimental to growth if the supply of other cations is low, and (c) there may be indirect effects associated with shifts in pH of the medium, such as the availability of Mo and P at low pH resulting from use of NH_4^+-N, and of heavy metals such as Mn and Fe at high pH values.

Some Solanaceous crops, e.g. tobacco (<u>Nicotiana tabaccum</u> L.) (McCants et al., 1959), tomato (Morris and Giddens, 1963; Pill and Lambeth, 1977; Wilcox et al., 1977), and potato (Volk and Gammon, 1952, 1954; Hendrickson et al., 1978) are known to grow better when a high NO_3^-/NH_4^+ ratio is available to them. The literature does not indicate, however, that this preference can be assumed for all crop species in the Solanaceae family. Contradictory results have been obtained for several crop species including tobacco (Gous et al., 1971; Elliott, 1970; Rhoads, 1972), and non-Solanaceae species such as ryegrass (Poletschny and Sommer, 1976), and cotton (Reeves et al., 1988).

In field studies using $^{15}NH_4NO_3$ and $NH_4{}^{15}NO_3$, Roberts and Cheng (1984) found that when supplied with both N forms together, potato preferentially took up NO_3^--N over NH_4^+-N.

Davis et al. (1986b) found that potato plant age did not alter the response of plant growth to NH_4^+-N as opposed to NO_3^--N.

The research that has examined the N form preference of potato, shows that when NH_4^+-N is abundant, and NO_3^--N is absent, the plant often does not do well. Under highly controlled conditions, when NH_4^+ is the only N form available to the plant, growth is unthrifty and stunted (Chen and Li, 1978; Davis et al., 1986b; Loescher, 1981; Polizotto et al., 1975), with reduced tuber weights (Davis, 1983; Davis et al., 1986b). Other reported effects of high NH_4^+-N include nutritional imbalances such as a greater requirement for K (Barker et al., 1967), reduced uptake of Ca and Mg, increased uptake of P (Davis et al., 1986b; Polizotto et al., 1975), reduced water uptake (Polizotto et al., 1975; Quebedeaux and Ozbun, 1973), altered metabolism such as decreased starch synthesis (Matsumoto et al., 1969), and reduced tuber quality (Middleton et al., 1975; Painter and Augustin, 1976; Hendrickson et al., 1978; Volk and Gammon, 1954).

Another symptom of excess NH_4^+-N and insufficient NO_3^--N nutrition, is small and weak looking plants, with chlorotic, tightly-rolled leaves (Davis et al., 1986b). This phenomenon is generally referred to as nutritional leaf roll (Volk and Gammon, 1952; 1954). In Florida, nutritional leaf roll is most severe on the very sandy and/or strongly

acidic soils, on relatively newly cleared lands, or recultivated land that has been in meadow for several years (Volk and Gammon, 1952; 1954). Volk and Gammon (1954) found that on highly acid soils, nutritional leaf roll was severe where the amount of soil NO_3^--N available to the plant was low, but it did not develop where NO_3^--N was high, regardless of NH_4^+-N concentrations in the soil. What they observed, therefore, was not an NH_4^+-N toxicity, but a NO_3^--N deficiency.

Ammonium nitrate fertilizer resulted in higher potato yields than did NH_4^+-N sources lacking in NO_3^--N in studies in Maine (Terman et al., 1951), north Florida (Volk and Gammon, 1954), and Germany (Meisinger et al., 1978). In other cases, NH_4^+-N sources resulted in greater potato yields than NO_3^--N or mixed sources in Wisconsin (Bundy et al., 1986) and eastern Washington (Davis et al., 1986a, 1986b). In such cases, the favorable response to NH_4^+-N, in contrast to NO_3^--N, is usually attributed to substantial leaching of NO_3^--N, as a result of heavy irrigation or rainfall (Davis et al., 1986a). In yet other field studies with potato, no significant differences in yield were found between NH_4^+-N and NO_3^--N sources in Maine (Brown et al., 1930), eastern Washington (Davis et al., 1986a), New Brunswick (MacLean 1983), and Michigan (Vitosh, 1971).

The conflicting results of these efforts to evaluate N fertilizer sources for potato production has in part been

due to the wide variety of cultural practices, soils, and climatic conditions in these studies (Bundy et al., 1986; Meisenger et al., 1978). Sanderson and White (1987) found that cultivars showed differential performance in response to N sources and rates, though Meisinger et al. (1978) and Rowberry and Johnston (1980) found no such cultivar difference. This contradiction was attributed to differences in the lengths of growing season from one region to another. In some studies, interactions between N rate effects, and differences in effects due to N source, have occurred (Giroux, 1982; Sanderson and White, 1987), while in other studies (Giroux, 1982; Rowberry and Johnston, 1980), no such interaction occurred.

Slow release N fertilizers such as IBDU and sulfur coated urea (SCU) have been compared to NH_4NO_3 as N sources for potato in North Florida. The NH_4NO_3 fertilizer outyielded the slow release N sources by 25 to 27%. Apparently, the slow release N sources did not release N sufficiently to meet the crop's requirements, and rainfall was light, limiting NO_3^--N leaching losses (Elkashif et al., 1983). Since these slow release N sources break down first to NH_4^+-N, releasing NO_3^--N only after nitrification commences, it is possible that these plants also suffered from a NO_3^--N deficiency.

Nitrogen Recovery

Leaching, denitrification, NH_3 volatilization, and other types of N losses result in N-use efficiency by crop plants as low as 20% and rarely higher than 80% of added plus native soil N (Amberger, 1981b; Blue and Graetz, 1977; Nelson et al., 1977; Prasad et al., 1971; Smirnov, 1968; 1978; Volk, 1956). Other causes of incomplete recovery of N from soil-plant systems include fertilizer-derived injury to plant roots or foliage and plant preference for NH_4^+-N or NO_3^--N. Meteorological conditions, management practices, and soil characteristics affect all of these factors (Hauck and Koshino, 1971). One factor that is often overlooked, is the immobilization of fertilizer N by heterotrophic soil microorganisms (Ashworth, 1986).

Asfary et al. (1983) found that apparent potato crop recovery of fertilizer N ranged from 50 to 71% without irrigation, and from 73 to 79% with irrigation. Bundy et al. (1986) found that although N concentration in the tubers was not affected by N source, the proportion of supplemental N recovered in tubers differed significantly among N sources. The order of increasing recoveries was $(NH_4)_2SO_4$ > urea = NH_4NO_3 > $Ca(NO_3)_2$. They also found that the proportion of added N recovered in the tubers decreased as applied N rates were increased.

Conclusions

The chemistry of DCD and nitrapyrin are fairly well understood. There is a reasonable understanding of the mechanism by which they inhibit nitrification, though more research should be done in this area. The longevity of inhibition and concentration effects of the inhibitors are quite variable, depending on environmental and soil conditions. The loss mechanisms for nitrapyrin (volatilization and hydrolysis) are fairly well understood, while those of DCD (leaching and decomposition) need further study. There is a need for more long term (three or more years) research on the effects of inhibitors on soil N transformations other than nitrification, soil N leaching and water quality, and total soil inorganic N.

Crop response to inhibitors in the greenhouse has been fairly predictable but field trials are another matter. More often than not, crop yields are not increased by nitrification inhibitors. The conditions under which favorable responses occur are subject to several interacting factors, making favorable responses almost impossible to predict. These interacting factors include N rate, leaching rainfall, soil drainage, immobilization and mineralization of fertilizer N, temperature, and time of fertilizer application. Some reasons for this have been proposed by Hauck (1972), McCormick et al. (1984), Blackmer (1986), and Ashworth (1986), Norman et al. (1989), and Walters and Malzer (1990a,

1990b). Chancy and Kamprath (1982) were the first researchers to clearly document that nitrification inhibitors inhibited nitrification while not increasing total inorganic N concentration in the soil. Other researchers reporting the effects of nitrification inhibitors on total soil inorganic N have done so indirectly or without statistical analysis.

CHAPTER 3
MATERIALS AND METHODS

Nitrogen and Amendments Applied to Potato

Experimental design. Potato (Solanum tuberosum L. cv. Atlantic) was grown in 1983, 1984, and 1985 at the AREC at Hastings in St. Johns County, and in 1983 and 1984, at the Horticulture Unit, at Gainesville, in Alachua County. The soil at the AREC Hastings (Table 3-1) was an Elzey fine sand (sandy, siliceous, hyperthermic Arenic Ochraqualf) (USDA, 1983). The soil at the Horticulture Unit was a Millhopper sand (loamy, siliceous, hyperthermic Grossarenic Paleudult) in 1983, and a Plummer fine sand (loamy, siliceous, thermic Grossarenic Paleaquult) in 1984 (USDA, 1985). Selected soil characteristics at harvest are shown in Table 3-2.

The experiment was a randomized complete block factorial design within each year and location, with four blocks. The factors were N rate and amendment. In 1983, there were two N rates, 134 and 202 kg N ha^{-1}. In 1984 and 1985, a third N rate, 67 kg ha^{-1} was added. In 1983 and 1984, ammonium nitrate was the N source. In 1985, N was applied as 75% NH_4^+-N and 25% NO_3^--N, supplied from a mixture of $(NH_4)_2SO_4$ and NH_4NO_3. At each N rate, two rates of DCD, 5.6 and 11.2 kg ha^{-1}, were compared to a control (no

Table 3-1. Classification of the soils used.

Location	Soil Series	Taxonomic Name
Gainesville 1983	Millhopper sand	Loamy, siliceous hyperthermic Grossarenic Paleudult
Gainesville 1984	Plummer fine sand	Loamy, siliceous hyperthermic Grossarenic Paleaquult
Hastings 1983	Elzey fine sand	Sandy, siliceous hyperthermic Arenic Ochraqualf
Hastings 1984	Elzey fine sand	Sandy, siliceous hyperthermic Arenic Ochraqualf
Hastings 1985	Elzey fine sand	Sandy, siliceous hyperthermic Arenic Ochraqualf
Live Oak 1985	Lakeland fine sand	Thermic, coated Typic Quartzipsamment

Table 3-2. Selected soil properties at harvest.

	pH	CEC	Sand	Silt	Clay	Organic C	Organic N
		cmol kg^{-1}	dag kg^{-1}				
Location & Year			Soils Planted to Potato†				
Gainesville 1983 Millhopper sand	4.9	8.11	84.5	11.4	4.4	2.1	0.129
Gainesville 1984 Plummer fine sand	5.6	3.07	90.7	4.9	4.4	0.8	0.045
Hastings 1983 Elzey fine sand	4.5	3‡	94.1	4.2	1.7	1.2	0.068
Hastings 1984 Elzey fine sand	5.2	2.70	94.7	0.9	4.4	1.0	0.056
Hastings 1985 Elzey fine sand	4.8	3.36	94.1	4.3	1.6	1.0	0.062
Depth (cm)				Fallow Soil			
0-15	5.3	4.04	92.3	6.0	1.7	1.2	0.055
15-30	5.2	3.30	91.9	5.6	2.5	1.0	0.036
30-61	4.8	2.06	92.2	5.4	2.4	0.6	0.021
61-91	4.6	1.04	92.7	4.8	2.5	0.3	0.010
91-122	4.5	0.90	92.9	4.5	2.6	0.2	0.008

†Sampled to a depth of 30-33 cm.
‡Estimated from data of USDA (1983).

amendment) and to two rates of nitrapyrin at 0.56 and 1.12 kg ha^{-1}. These two nitrification inhibitors were compared to a slow release N form, IBDU as one-third of the total N applied. For statistical purposes, these six treatments (a control, two DCD rates, two nitrapyrin rates, and one IBDU rate) were considered six rates of the factor amendment.

Dicyandiamide (obtained from SKW Trostberg A.G.) powder was ground to pass a 2 mm sieve and coated onto NH_4NO_3 using vegetable oil as an adherent (German Patent Specification No. 2 531 962, cited in Rieder and Michaud, 1980). Liquid nitrapyrin was poured onto the fertilizer mixtures and mixed just prior to fertilizer application.

In all three years, 12 kg ha^{-1} P as triple superphosphate, 186 kg ha^{-1} K as K_2SO_4, 34 kg ha^{-1} Mg as MgO and 56 kg ha^{-1} of TM300 micronutrient mix were applied pre-plant. The TM300 contained 2.40% B, 2.40% Cu, 14.4% Fe, 6.00% Mn, 0.06% Mo, and 5.60% Zn by weight. In 1985, K was applied in two equal applications. Fertilizers were applied in two bands 5 cm deep and 5 cm on each side of the potato seed pieces.

At Hastings, four row plots were used. Each row was 1.02 x 4.5 m. At Gainesville, one row plots were used. Each row was 1.02 x 12.2 m. Potato seed pieces were planted in bedded rows 25 to 31 cm high, about 51 cm wide at the base and 15 to 21 cm wide at the top. The seed pieces were

cut and coated with the fungicide cis-N-trichloromethylthio-4-cyclohexene-1,2-dicarboximide (captan) and planted 20 cm apart in the row.

Standard cultural practices for Northeast Florida potato production were followed. The soil nematicide D-D (a mixture of dichloropropene and dichloropropane) was applied to the soil at a rate of 31 L ha^{-1} 2 to 6 weeks prior to planting. The herbicide 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one (metribuzin), at 0.28 kg ha^{-1} of active ingredient, was applied 11 to 20 days after planting (dap) at Gainesville. At Hastings, a combination of metribuzin and N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitro-benzenamine (pendimethalin) was used. Vine killer was not used prior to harvest at either location. The insecticide 2-methyl-2(methylthio)-propionaldehyde-O(methylcarbamoyl)oxime (aldicarb) was used at planting at Hastings. All plots were cultivated periodically to control weeds and reverse bed erosion. At Gainesville, overhead sprinkler irrigation and surface ditch drainage were used. At Hastings, subsoil, i.e., seepage or water furrow irrigation-drainage was used.

Plant sampling. Tubers were harvested at maturity, graded according to U.S. Grade Standards and weighed. The grades were PK (pickouts) rotten and green tubers, G&NG (grader and harvester damaged), B (3.8 to 4.8 cm), A1 (4.8 to 6.35 cm), A2 (6.35 to 7.6 cm), and A3 (7.6 to 9.5 cm) in

diameter. Subsamples were taken of harvested grade A tubers for the measurement of specific gravity, tuber dry weight, and tuber N concentration.

Whole plant samples were taken to measure above ground (shoot) phytomass and total shoot N concentration just before harvest in 1983 and 1984. Whole leaf samples, i.e., blade plus petiole, were taken periodically during the growing season in all three years (Table 3-3) and were analyzed for total N concentration (Bremner, 1965). Leaf N concentration at tuber initiation (43 to 55 dap) was measured in all five location-year combinations (growth stages according to Kleinkopf et al., 1981). Leaf N concentration at flowering (66 to 81 dap), which corresponds to the tuber bulking stage, was measured at all locations and in all years except in 1983 at Hastings. Leaf N concentration at the tuber maturation stage was measured in samples taken just before harvest (93 to 98 dap) in 1983 and 1984.

Soil sampling. Composite soil samples were taken to a depth of 33 cm in each field in 1983 and 1984 for the purpose of soil characterization. Soil was sampled with a 4.8 cm i.d. tube at two to four week intervals (Table 3-3) in the beds down to the tillage pan at a depth of 33 cm for determination of extractable soil inorganic N. Samples were taken from the soil both adjacent to and away from the fertilizer bands and all such samples from each plot were composited. At Hastings, 12 cores were taken from each plot.

Table 3-3. Timing of soil and leaf sampling in potato fields.

	Days after Planting				
	Gainesville		Hastings		
Potato Growth Stage	1983	1984	1983	1984	1985
			Soil Sampling		
Near planting	-	-	5	6	-
Emergence	16	13	-	18	-
Vegetative	35	31	31	32	-
Tuber initiation	-	45	-	46	-
Tuber bulking	59	69	61	74	-
At harvest	98	108	-	103	-
			Leaf Sampling		
Early (tuber initiation)	43	48	54	55	51
Flowering (tuber bulking)	66	74	-	81	73
Late (tuber maturation)	93	94	95	98	-

At Gainesville, 9 cores were taken per plot. The samples were placed in polyethylene bags, cooled during transport to the lab, and frozen until extraction and analysis.

Analytical procedures. Leaf, shoot, and tuber N concentrations were determined using a semimicro-Kjeldahl block digestion and distillation procedure (Nelson and Sommers, 1972). Tuber specific gravity (SG) was measured by comparing tuber fresh weights in air and submerged in water. The formula used was

$$SG = \frac{(TUWA - TRWA)}{(TUWA - TRWA) - (TUWW - TRWW)}$$

where

TUWA = tuber weight in air
TRWA = tare weight in air
TUWW = tuber weight in water
TRWW = tare weight in water.

Tuber subsamples were cut, dried and ground for determination of dry weight and analyzed for N concentration.

Soil pH was determined using a 2:1 water:soil ratio. Soil organic carbon was quantified using a modified Walkley-Black procedure (Allison, 1965). Total soil N was determined using a semimicro-Kjeldahl block digestion and distillation procedure (Nelson and Sommers, 1972). Cation exchange capacity was measured by Na^+/NH_4^+ exchange using a leaching technique with the salts being buffered to pH 7

(Schollenberger and Simon, 1945). Particle size distribution was determined by the pipette method (Day, 1965).

Soil inorganic N (ammonium and nitrate plus nitrite) was extracted for one hour with 1 M KCl containing 15 mg L^{-1} of phenyl mercuric acetate as a bactericide (Bremner, 1965). This extract was distilled into boric acid indicator for determination of NH_4^+-N and NO_3^--N concentrations. Soil DCD concentrations were determined using a modification of Vilsmeier's (1979, 1982) method. The naphthol reagent was filtered through a 0.45 µm filter rather than being centrifuged. Because the naphthol reagent is unstable, a new batch was made up each day. Because of this instability the same blank solution could not be used for all the samples and standards in a set. Therefore, a separate blank was used for each group of six samples or standards. The blanks used for the standards were 0.01 M $CaCl_2$. The blanks used for the soil extract samples were extracts of soil from plots which received 0 kg ha^{-1} DCD and the same N rate as the sampled soil.

Statistical procedures. Statistical analyses of potato yield and other plant data, and soil inorganic N data were carried out with Statistical Analysis System (SAS), a computer system for data analysis (SAS Institute Inc., 1982a, 1982b, 1983, 1985a, 1985b; Freund and Littel, 1981; Helwig, 1983). Analysis of variance was carried out with the PROC GLM procedure and orthogonal single degree of

freedom contrasts. The control treatment was considered the lowest of three DCD treatment rates. Five orthogonal contrasts were used for the inhibitor and IBDU treatments. These were: DCD rate linear, DCD rate quadratic, nitrapyrin rate (0.56 v 1.12 kg ha^{-1} nitrapyrin), DCD v nitrapyrin (5.6 and 11.2 kg ha^{-1} DCD v 0.56 and 1.12 kg ha^{-1} nitrapyrin), and IBDU v inhibitors. In 1984 and 1985, the effects of the three N rates were analyzed with linear and quadratic contrasts. Where the effects of N rate and amendment interacted, the data were subsetted so that the effects of each factor (N rate and amendment) could be analyzed at each rate of the other factor. As a result of crop damage, there were two missing cells at Gainesville, in 1983. Thus the plant response means for this experiment are least square means computed by the LSMEANS statement in SAS.

Urea and DCD Applied to a Fallow Quartzipsamment

Experimental design. A study was conducted at the AREC at Live Oak in Suwannee County on a Lakeland fine sand (thermic, coated Typic Quartzipsamment) to evaluate the effectiveness of DCD as a nitrification inhibitor and to determine the effects of DCD application on concentrations of DCD, NH_4^+-N, and NO_3^--N in the soil profile over time. Selected soil properties are shown in Table 3-2. A randomized complete block design with four blocks was used. Dicyandiamide was applied at rates of 0, 20, 40, and 60 kg ha^{-1}. Nitrogen as urea was broadcast and incorporated at

the rate of 200 kg N ha^{-1} to all plots on March 29, 1985. The urea and DCD were thoroughly mixed together by spraying the urea with 0.5% water and 0.5% vegetable oil with an air sprayer, adding the DCD and mixing until uniform. The plots were 3.65 x 7.5 m. The plots remained fallow during the study and were kept free of weeds by cultivation.

Soil sampling and analysis. The fallow soil was sampled at approximately two week intervals starting 14 days after fertilizer application. Four cores were taken from each plot and all four cores for each depth were mixed together on each sampling date. The depths sampled were 0 to 15 cm, 15 to 30 cm, 30 to 61 cm, 61 to 91 cm, and 91 to 122 cm. The soil samples were analyzed for inorganic NH_4^+-N and NO_3^--N concentrations by KCl extraction and distillation (Bremner, 1965). Soil DCD concentrations were measured by the modification of the method of Vilsmeier (1979, 1982) mentioned above.

Statistical procedures. Analysis of variance was carried out with the PROC GLM procedure and orthogonal single degree of freedom contrasts (DCD rate linear, quadratic and cubic).

CHAPTER 4
TUBER YIELD, PLANT N CONTENT, AND BIOMASS

Tuber Yield

N rate effects. Marketable (grades A and B) and total tuber yield increased with increases in N rate in four of five year-location combinations. In 1983 at Hastings, marketable tuber yield increased from 18.6 to 21.7 t ha^{-1} with an increase in N rate from 134 to 202 kg ha^{-1} (Table 4-1). In 1983 at Gainesville, marketable yield was not influenced by N rate. In 1984, an increase in N rate from 67 to 134 kg ha^{-1} resulted in an increase in marketable tuber yield from 24.8 to 29.0 t ha^{-1} at Gainesville, and from 16.7 to 21.1 t ha^{-1} at Hastings. A further increase in N rate from 134 to 202 kg ha^{-1}, did not influence marketable tuber yield at either location in 1984. In 1985 at Hastings, marketable tuber yield increased from 29.9 to 33.8 t ha^{-1} with an increase in N rate from 67 to 134 kg ha^{-1}. A further increase in N rate to 202 kg ha^{-1} had no effect. Nitrogen rate and all other treatment effects on total tuber yield (Table 4-2) were similar to affects on marketable tuber yield in all three years and at both locations.

Amendment effects. In 1983 at Hastings, DCD rate interacted with N rate effects on marketable tuber yield

Table 4-1. Effects of N rate and amendment on marketable tuber yield.

	Gainesville	
Treatment	1983	1984
	t/ha	
N Rate (kg/ha)		
67	-†	24.8
134	26.7(23)‡	29.0
202	27.4(22)	29.0
	NS	L** Qx
Amendment		
Control	28.8(8)	29.7
5.6 kg/ha DCD	25.7(8)	28.0
11.2 kg/ha DCD	26.5(7)	28.9
0.56 kg/ha Nty§	26.7(8)	26.0
1.12 kg/ha Nty	26.4(8)	25.7
IBDU (1/3 of N)	28.5(6)	27.3
Significance		
DCD Linear	NS	NS
DCD Quadratic	NS	NS
Nty Rate	NS	NS
DCD v Nty	NS	*
IBDU v Ih#	NS	NS
Interactions	NS	Nty R X NR L*

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

†Rate not included in 1983.
‡Gainesville 1983 means are least square means. Number of observations are in parentheses.
§Nty = nitrapyrin.
#Ih = inhibitors.

Table 4-1--Extended.

Hastings		
1983	1984	1985
t/ha		
-	16.7	29.9
18.6	21.1	33.8
21.7	23.7	34.5
L***	L***	L***
	Qx	Q*
18.3	20.6	33.3
21.0	21.5	33.4
21.4	21.2	33.4
18.0	19.3	31.2
21.5	19.7	32.1
20.7	20.9	32.9
*	NS	NS
NS	NS	NS
*	NS	NS
NS	**	*
NS	NS	NS
DCD Q X NR **	IBDU v Ih X NR L *	NS

Table 4-2. Effects of N rate and amendment on total tuber yield.

	Gainesville	
Treatment	1983	1984
	t/ha	
<u>N Rate (kg/ha)</u>		
67	-[†]	25.7
134	27.9(23)[‡]	30.2
202	29.0(22)	30.1
	NS	L**
		Q*
<u>Amendment</u>		
Control	29.8(8)	30.6
5.6 kg/ha DCD	27.4(8)	29.1
11.2 kg/ha DCD	27.7(7)	29.8
0.56 kg/ha Nty[§]	28.1(8)	27.3
1.12 kg/ha Nty	27.7(8)	26.8
IBDU (1/3 of N)	30.1(6)	28.5
<u>Significance</u>		
DCD Linear	NS	NS
DCD Quadratic	NS	NS
Nty Rate	NS	NS
DCD v Nty	NS	x
IBDU v Ih[#]	NS	NS
<u>Interactions</u>	NS	Nty R X NR L *

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[‡]Rate not included in 1983.
[‡]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[§]Nty = nitrapyrin.
[#]Ih = inhibitors.

Table 4-2--Extended.

Hastings		
1983	1984	1985
t/ha		
-	17.9	32.8
18.7	22.6	36.9
21.8	25.5	36.8
L**	L***	L***
	Qx	Q**
18.3	21.9	35.8
21.1	23.0	36.1
21.5	22.7	36.2
18.1	20.8	34.4
21.6	21.2	34.8
20.8	22.3	35.7
*	NS	NS
NS	NS	NS
*	NS	NS
NS	**	*
NS	NS	NS
DCD Q X NR **	IBDU v Ih X NR L *	NS

(Table 4-3). With 134 kg ha^{-1} N, marketable yield increased from 14.6 to 21.7 t ha^{-1} with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. A further increase in DCD to 11.2 kg ha^{-1} had no effect on marketable yield. With 202 kg ha^{-1} N, DCD rate had no effect on marketable yield. Dicyandiamide rate had no effect on marketable or total tuber yield in 1983 or 1984 at Gainesville, or in 1984 or 1985 at Hastings.

In 1983 at Hastings, marketable tuber yield increased from 18.0 to 21.5 t ha^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1} (Table 4-1). In 1984 at Gainesville, nitrapyrin rate interacted with N rate effects on tuber yield (Table 4-4). With 67 kg ha^{-1} N, marketable yield increased from 21.3 to 26.6 t ha^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 134 and 202 kg ha^{-1} N, tuber yield was not affected by nitrapyrin rate.

In 1983 at Gainesville and Hastings, tuber yield means were similar with DCD and nitrapyrin (Table 4-1). In 1984 at both locations, and in 1985 at Hastings, tuber yield means were higher with DCD than with nitrapyrin. In 1984 at Gainesville, marketable yield means were 28.4 t ha^{-1} with DCD and 25.8 t ha^{-1} with nitrapyrin. In 1984 at Hastings, marketable yield means were 21.4 t ha^{-1} with DCD and 19.5 t ha^{-1} with nitrapyrin. In 1985 at Hastings, marketable yield means were 33.4 t ha^{-1} with DCD and 31.6 t ha^{-1} with nitrapyrin.

Table 4-3. Interaction (DCD Q X NR **) of DCD and N rate effects on tuber yield (Hastings, 1983).

	DCD Rate (kg/ha)		
N Rate	0	5.6	11.2
kg/ha		Marketable Yield (t/ha)	
134	14.6	21.7	19.2 L**Q**
202	21.9	20.2	23.5 NS
	*	NS	x
		Total Yield (t/ha)	
134	14.7	21.8	19.3 L**Q**
202	21.9	20.3	23.6 NS
	*	NS	x

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), or 0.01 (**) probability levels, respectively.

Table 4-4. Interaction (Nty R X NR L *) of nitrapyrin and N rate effects on tuber yield (Gainesville, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	Marketable Yield (t/ha)	
67	21.3	26.6 x
134	29.0	26.2 NS
202	27.7	24.4 NS
	L*Q*	NS
	Total Yield (t/ha)	
67	22.0	27.6 x
134	30.1	27.0 NS
202	29.6	25.7 NS
	L*Qx	NS

Nonsignificant (NS) or significant at the 0.1 (x), or 0.05 (*)probability levels, respectively.

Marketable and total yields in 1984 at Hastings, were influenced by an interaction between the IBDU v inhibitor contrast, and N rate (Table 4-5). With 67 kg ha^{-1} N, marketable yield means were higher with IBDU (18.3 t ha^{-1}) than with inhibitors (16.3 t ha^{-1}). With 134 and 202 kg ha^{-1} N, tuber yield means were similar with IBDU and inhibitors.

Proportion of Marketable Tuber Yield That Was Grade A

N rate effects. The proportion of marketable yield that was grade A (Table 4-6), increased with increasing N rate in all year-location combinations except in 1983 at Gainesville. In 1984 at Gainesville, the proportion of marketable yield that was grade A increased from 80.4 to 84.2% with an increase in N rate from 67 to 134 kg ha^{-1}. A further increase in N to 202 kg ha^{-1} had no effect.

In 1983 at Hastings, the proportion of marketable yield that was grade A increased from 74.6 to 77.6% with an increase in N rate from 67 to 134 kg ha^{-1}. In 1984 at Hastings, the proportion of marketable yield that was grade A increased from 84.6 to 88.5% with an increase in N rate from 67 to 134 kg ha^{-1}. A further increase in N to 202 kg ha^{-1} had no affect. In 1985 at Hastings, N and DCD rate interacted in their effects on the proportion of marketable yield that was grade A (Table 4-7). With 0 DCD, N rate had no effect. With 5.6 and 11.2 kg ha^{-1} DCD, the proportion of marketable yield that was grade A increased with an increase

Table 4-5. Interaction (IBDU v Ih X NR L *) of IBDU v inhibitors, and N rate effects on tuber yield (Hastings, 1984).

N Rate	IBDU	Inhibitors
kg/ha	Marketable Yield (t/ha)	
67	18.3	16.3 x
134	21.7	20.9 NS
202	22.9	24.1 NS
	L***	L***
	Total Yield (t/ha)	
67	19.5	17.5 *
134	23.0	22.5 NS
202	24.4	25.9 NS
	L***	L***

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

Table 4-6. Effects of N rate and amendment on the proportion of marketable yield that was grade A.

Treatment	Gainesville 1983	Gainesville 1984	Hastings 1983	Hastings 1984	Hastings 1985
	%				
N Rate (kg/ha)					
67	-[†]	80.4	-	84.6	89.4
134	91.8(23)[‡]	84.2	74.6	88.5	92.2
202	92.1(22)	84.6	77.6	89.4	93.1
	NS	L**	*	L***	L***
		Qx		Q*	Q*
Amendment					
Control	92.5(8)	85.3	73.3	87.6	92.0
5.6 kg/ha DCD	91.0(8)	83.5	76.7	87.3	91.3
11.2 kg/ha DCD	92.6(7)	84.3	79.3	87.9	91.9
0.56 kg/ha Nty[§]	91.7(8)	82.2	73.7	86.1	91.2
1.12 kg/ha Nty	90.9(8)	80.5	78.8	87.2	90.8
IBDU (1/3 of N)	92.9(6)	82.7	74.8	88.8	92.1
Significance					
DCD Linear	NS	NS	*	NS	NS
DCD Quadratic	x	NS	NS	NS	NS
Nty Rate	NS	NS	*	NS	NS
DCD v Nty	NS	*	NS	NS	NS
IBDU v Ih[¶]	NS	NS	NS	*	NS
Interactions	NS	NS	NS	NS	DCD L X NR L * IBDU v Ih X NR L *

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[†]Rate not included in 1983.
[‡]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[§]Nty = nitrapyrin.
[¶]Ih = inhibitors.

Table 4-7. Interaction (DCD L X NR L *) of DCD and N rate effects on the proportion of marketable yield that was grade A (Hastings, 1985).

N Rate	DCD Rate (kg/ha)		
	0	5.6	11.2
kg/ha	%		
67	90.5	88.4	88.6 NS
134	92.9	92.1	92.5 NS
202	92.7	93.4	94.7 NS
	NS	L**	L***

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table 4-8. Interaction (IBDU v Ih X NR L *) of IBDU v inhibitors, and N rate effects on the proportion of marketable yield that was grade A (Hastings, 1985).

N Rate	IBDU	Inhibitors
kg/ha	%	
67	91.3	88.6 *
134	92.6	91.9 NS
202	92.5	93.3 NS
	NS	L**
	Qx	

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), or 0.01 (**) probability levels, respectively.

in N rate from 67 to 202 kg ha^{-1}. With 5.6 kg ha^{-1} DCD, the proportion of marketable yield that was grade A increased from 88.4 to 93.4% with an increase in N rate. With 11.2 kg ha^{-1} DCD, the proportion of marketable yield that was grade A increased from 88.6 to 94.7% with an increase in N rate.

Amendment effects. In 1983 at Hastings, the proportion of marketable yield that was grade A increased from 73.3 to 79.3% with an increase in DCD rate from 0 to 11.2 kg ha^{-1}. The proportion of marketable yield that was grade A increased from 73.7 to 78.8% with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1} in 1983 at Hastings.

In 1984 at Gainesville, the proportion of marketable yield that was grade A was higher with DCD (83.9%) than with nitrapyrin (81.4%) (Table 4-6). In 1984 at Hastings, the proportion of marketable yield that was grade A was higher with IBDU treatments (88.8%) than with inhibitors (87.1%). In 1985 at Hastings, the IBDU v inhibitor contrast interacted with N rate (Table 4-8). With 67 kg ha^{-1} N, the proportion of marketable yield that was grade A was higher with IBDU (91.3%) than with inhibitors (88.6%). With 134 and 202 kg ha^{-1} N, the proportion of marketable yield that was grade A was similar with IBDU and inhibitors.

Proportion of Total Tuber Yield That Was Marketable

N rate effects. In 1985 at Hastings, the proportion of total yield that was marketable (Table 4-9), was similar with N rates of 67 and 134 kg ha^{-1} but was increased from 91.5 to 93.6% with an increase in N rate from 134 to 202 kg ha^{-1}.

Amendment effects. In 1984 at Gainesville, the DCD v nitrapyrin contrast interacted with N rate (Table 4-10). With 202 kg ha^{-1} N, the proportion of total yield that was marketable was higher with DCD (97.0%) than with nitrapyrin (93.9%). With 67 and 134 kg ha^{-1} N, the proportion of total yield that was marketable was similar with the two inhibitors. In 1983 at Hastings, IBDU v inhibitors interacted with N rate (Table 4-11). With 202 kg ha^{-1} N, the proportion of total yield that was marketable was higher with inhibitors (99.7%) than with IBDU (99.1%). With 134 kg ha^{-1} N, the proportion of total yield that was marketable was similar with the two types of amendments.

Tuber Specific Gravity

N rate effects. Tuber specific gravity increased from 1.0841 to 1.0854 as N rate increased from 134 to 202 kg ha^{-1} in 1983 at Hastings (Table 4-12). In 1984 at Hastings, tuber specific gravity increased from 1.0769 to 1.0796 as N rate increased from 67 to 202 kg ha^{-1}. In 1985 at Hastings, tuber specific gravity increased from 1.0775 to 1.0791 with

Table 4-9. Effects of N rate and amendment on the proportion of total yield that was marketable.

Treatment	Gainesville 1983	Gainesville 1984	Hastings 1983	Hastings 1984	Hastings 1985
	%				
N Rate (kg/ha)					
67	-[†]	96.0	-	93.4	91.1
134	95.6(23)[‡]	95.7	99.6	93.3	91.5
202	94.6(22)	95.8	99.6	93.2	93.6
	NS	NS	NS	NS	L*** Qx
Amendment					
Control	96.5(8)	96.8	99.8	94.2	93.0
5.6 kg/ha DCD	93.8(8)	95.8	99.6	93.4	92.5
11.2 kg/ha DCD	95.6(7)	96.6	99.6	93.1	91.9
0.56 kg/ha Nty[§]	94.8(8)	94.6	99.5	92.6	91.0
1.12 kg/ha Nty	95.1(8)	96.0	99.6	92.7	92.0
IBDU (1/3 of N)	94.8(6)	95.3	99.5	93.7	92.0
Significance					
DCD Linear	NS	NS	NS	NS	NS
DCD Quadratic	NS	NS	NS	NS	NS
Nty Rate	NS	NS	NS	NS	NS
DCD v Nty	NS	NS	NS	NS	NS
IBDU v Ih[¶]	NS	NS	NS	NS	NS
Interactions	NS	DCD v Nty X NR Q *	IBDU v Ih X NR *	NS	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[†]Rate not included in 1983.
[‡]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[§]Nty = nitrapyrin.
[¶]Ih = inhibitors.

Table 4-10. Interaction (DCD v nitrapyrin X NR Q *) of DCD v nitrapyrin, and N rate effects on the proportion of total yield that was marketable (Gainesville, 1984).

N Rate	DCD	Nitrapyrin
kg/ha	%	
67	96.8	95.4 NS
134	94.8	96.4 NS
202	97.0	93.9 *
	Q*	NS

Nonsignificant (NS) or significant at the 0.05 (*) probability level.

Table 4-11. Interaction (IBDU v Ih X NR *) of IBDU v inhibitors, and N rate effects on the proportion of total yield that was marketable (Hastings, 1983).

N Rate	IBDU	Inhibitors
kg/ha	%	
134	99.8	99.6 NS
202	99.1	99.7 *
	NS	NS

Nonsignificant (NS) or significant at the 0.05 (*) probability level.

Table 4-12. Effects of N rate and amendment on tuber specific gravity.

	Gainesville		Hastings		
Treatment	1983	1984	1983	1984	1985
N Rate (kg/ha)					
67	–[†]	1.0754	–	1.0769	1.0775
134	1.0892(23)[‡]	1.0732	1.0841	1.0787	1.0791
202	1.0909(22)	1.0741	1.0854	1.0796	1.0784
	NS	NS	x	L***	Q*
Amendment					
Control	1.0882(8)	1.0742	1.0845	1.0778	1.0786
5.6 kg/ha DCD	1.0892(8)	1.0723	1.0832	1.0773	1.0779
11.2 kg/ha DCD	1.0908(7)	1.0738	1.0851	1.0781	1.0762
0.56 kg/ha Nty[§]	1.0932(8)	1.0754	1.0857	1.0787	1.0787
1.12 kg/ha Nty	1.0880(8)	1.0766	1.0854	1.0798	1.0797
IBDU (1/3 of N)	1.0910(6)	1.0732	1.0846	1.0786	1.0789
Significance					
DCD Linear	NS	NS	NS	NS	**
DCD Quadratic	NS	NS	NS	NS	NS
Nty Rate	x	NS	NS	NS	NS
DCD v Nty	NS	x	NS	*	***
IBDU v Ih[¶]	NS	NS	NS	NS	NS
Interactions	NS	NS	DCD Q X NR * DCD v Nty X NR *	None	None

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[†]Rate not included in 1983.
[‡]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[§]Nty = nitrapyrin.
[¶]Ih = inhibitors.

an increase in N rate from 67 to 134 kg ha^{-1}, then decreased to 1.0784 with a further increase in N rate to 202 kg ha^{-1}. Tuber specific gravity was not influenced by N rate in 1983 or 1984 at Gainesville.

<u>Amendment effects</u>. In 1983 at Hastings, DCD rate interacted with N rate effects on tuber specific gravity (Table 4-13). With 202 kg ha^{-1} N, tuber specific gravity decreased from 1.0862 to 1.0818 with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. With a further increase in DCD to 11.2 kg ha^{-1}, tuber specific gravity increased to 1.0856. With 134 kg ha^{-1} N, DCD rate had no effect on tuber specific gravity. In 1985 at Hastings, tuber specific gravity decreased from 1.0786 to 1.0762 with an increase in DCD rate from 0 to 11.2 kg ha^{-1} (Table 4-12).

In 1983 at Gainesville, tuber specific gravity decreased from 1.0932 to 1.0880 with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1} (Table 4-12). Tuber specific gravity was not influenced by nitrapyrin rate in 1983, 1984, or 1985 at Hastings, or in 1984 at Gainesville.

In 1984 at Gainesville and Hastings, and in 1985 at Hastings, tuber specific gravity was higher with the nitrapyrin treatments than with the DCD treatments (Table 4-12). In 1984 at Gainesville, tuber specific gravity was 1.0760 with nitrapyrin and 1.0730 with DCD. In 1984 at Hastings, tuber specific gravity was 1.0792 with nitrapyrin and 1.0777

Table 4-13. Interaction (DCD Q X NR *) of DCD and N rate effects on tuber specific gravity (Hastings, 1983).

	DCD Rate (kg/ha)		
N Rate	0	5.6	11.2
kg/ha			
134	1.0828	1.0845	1.0846 NS
202	1.0862	1.0818	1.0856 Q*
	x	NS	NS

Nonsignificant (NS) or significant at the 0.1 (x), or 0.05 (*) probability levels, respectively.

Table 4-14. Interaction (DCD v nitrapyrin X NR *) of DCD v nitrapyrin, and N rate effects on tuber specific gravity (Hastings, 1983).

N Rate	DCD	Nitrapyrin
kg/ha		
134	1.0845	1.0841 NS
202	1.0837	1.0870 *
	NS	**

Nonsignificant (NS) or significant at the 0.05 (*), or 0.01 (**) probability levels, respectively.

with DCD. In 1985 at Hastings, tuber specific gravity was 1.0792 with nitrapyrin and 1.0770 with DCD.

In 1983 at Hastings, the DCD v nitrapyrin contrast interacted with the N rate effect on tuber specific gravity (Table 4-14). With 202 kg ha^{-1} N, tuber specific gravity was higher with nitrapyrin (1.0870) than with DCD (1.0837). With 134 kg ha^{-1} N, tuber specific gravity was similar with the two inhibitors.

Tuber N Concentration

N rate effects. Tuber N concentration means increased with increases in N rate in all five year-location combinations (Table 4-15). In 1983 at both locations, tuber N concentration increased from 0.98% with 134 kg ha^{-1} N, to 1.07-1.08% with 202 kg ha^{-1} N. In 1984, with an increase in N rate from 67 to 202 kg ha^{-1}, tuber N concentration increased from 1.23 to 1.62% at Gainesville, and from 1.12 to 1.33% at Hastings. In 1985 at Hastings, tuber N concentration was not measured.

Amendment effects. In 1983 at Hastings, DCD rate interacted with N rate effects on tuber N concentration (Table 4-16). With 134 kg ha^{-1} N, tuber N concentration increased from 0.92 to 1.02% with an increase in DCD rate from 0 to 5.6 kg ha^{-1} and did not increase further with an increase in DCD to 11.2 kg ha^{-1}. With 202 kg ha^{-1} N, tuber N concentration was not affected by an increase in DCD rate

Table 4-15. Effects of N rate and amendment on tuber N concentration in 1983 and 1984.

	Gainesville		Hastings	
Treatment	1983	1984	1983	1984
	% N			
N Rate (kg/ha)				
67	-†	1.23	-	1.12
134	0.98(22)‡	1.46	0.98	1.21
202	1.08(21)	1.62	1.07	1.33
	L**	L***	L***	L***
Amendment				
Control	0.97(8)	1.40	0.98	1.22
5.6 kg/ha DCD	1.01(7)	1.44	1.02	1.19
11.2 kg/ha DCD	1.00(7)	1.45	1.06	1.23
0.56 kg/ha Nty§	1.02(8)	1.43	0.96	1.24
1.12 kg/ha Nty	1.06(8)	1.45	1.10	1.20
IBDU (1/3 of N)	1.13(5)	1.45	1.02	1.22
Significance				
DCD Linear	NS	NS	*	NS
DCD Quadratic	NS	NS	NS	NS
Nty Rate	x	NS	***	NS
DCD v Nty	NS	NS	NS	NS
IBDU v Ih¶	x	NS	NS	NS
Interactions	NS	DCD L X NR L *	DCD Q X NR * Nty R X NR *	DCD v Nty X NR L x

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

†Rate not included in 1983.
‡Gainesville 1983 means are least square means. Number of observations are in parentheses.
§Nty = nitrapyrin.
¶Ih = inhibitors.

Table 4-16. Interaction (DCD Q X NR *) of DCD and N rate effects on tuber N concentration (Hastings, 1983).

N Rate	DCD Rate, (kg/ha) 0	5.6	11.2	
kg/ha	% N			
134	0.92	1.02	0.98	Qx
202	1.05	1.04	1.13	LxQx
	NS	NS	NS	

Nonsignificant (NS) or significant at the 0.1 (x), or 0.05 (*) probability levels, respectively.

Table 4-17. Interaction (DCD L X NR L *) of DCD and N rate effects on tuber N concentration (Gainesville, 1984).

N Rate	DCD Rate (kg/ha) 0	5.6	11.2	
kg/ha	% N			
67	1.26	1.24	1.15	L*
134	1.40	1.43	1.50	Lx
202	1.55	1.64	1.69	L**
	L***	L***	L***	
		Qx		

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

from 0 to 5.6 kg ha^{-1}, but increased from 1.04 to 1.13% with an increase in DCD rate to 11.2 kg ha^{-1}.

In 1984 at Gainesville, DCD rate interacted with N rate effects on tuber N concentration (Table 4-17). With 67 kg ha^{-1} N, tuber N concentration decreased from 1.26 to 1.15% with an increase in DCD rate from 0 to 11.2 kg ha^{-1}. With 134 kg ha^{-1} N, tuber N concentration increased from 1.40 to 1.50% with an increase in DCD rate from 0 to 11.2 kg ha^{-1}. With 202 kg ha^{-1} N, tuber N concentration increased from 1.55 to 1.69% with an increase in DCD rate from 0 to 11.2 kg ha^{-1}.

In 1983 at Gainesville, tuber N concentration increased from 1.02 to 1.06% with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1} (Table 4-15). In 1983 at Hastings, nitrapyrin rate interacted with N rate effects on tuber N concentration (Table 4-18). With 202 kg ha^{-1} N, tuber N concentration increased from 0.99 to 1.20% with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 134 kg ha^{-1} N, tuber N concentration was not affected by nitrapyrin rate.

In 1984 at Hastings, the DCD v nitrapyrin contrast interacted with N rate effects on tuber N concentration means (Table 4-19). With 202 kg ha^{-1} N, tuber N concentration means were higher with DCD (1.36%) than with nitrapyrin (1.27%). With 67 and 134 kg ha^{-1} N, tuber N concentration means were similar with the two inhibitors.

Table 4-18. Interaction (Nty R X NR *) of nitrapyrin and N rate effects on tuber N concentration (Hastings, 1983).

N Rate	Nitrapyrin Rate (kg/ha) 0.56	1.12
kg/ha	% N	
134	0.93	1.00 NS
202	0.99	1.20 ***
	NS	*

Nonsignificant (NS) or significant at the 0.05 (*) or 0.001 (***) probability levels, respectively.

Table 4-19. Interaction (DCD v nitrapyrin X NR L x) of DCD v nitrapyrin, and N rate effects on tuber N concentration (Hastings, 1984).

N Rate	DCD	Nitrapyrin
kg/ha	% N	
67	1.10	1.14 NS
134	1.19	1.25 NS
202	1.36	1.27 x
	L***	L*

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

In 1983 at Gainesville, tuber N concentration means were higher with IBDU (1.13%) than with inhibitors (1.02%) (Table 4-15).

Plant Shoot Biomass at Harvest

N rate effects. In 1983 at Gainesville, plant shoot biomass (Table 4-20), increased from 0.89 to 1.08 t ha^{-1} with an increase in N rate from 134 to 202 kg ha^{-1}, while at Hastings, plant shoot biomass increased from 0.65 to 0.81 t ha^{-1} with the same increase in N rate. In 1984 at Gainesville, plant shoot biomass increased from 0.88 to 1.41 t ha^{-1} with an increase in N rate from 67 to 202 kg ha^{-1}, while at Hastings, plant shoot biomass decreased from 1.12 to 0.71 t ha^{-1} with the same increase in N rate.

Amendment effects. In 1984 at Gainesville, nitrapyrin and N rate interacted in their effects on plant shoot biomass (Table 4-21). With 202 kg ha^{-1} N, plant shoot biomass decreased from 1.55 to 1.16 t ha^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 67 and 134 kg ha^{-1} N, plant shoot biomass was not influenced by nitrapyrin rate.

Total Biomass at Harvest

N rate effects. Total potato plant (plant shoots plus tubers) biomass at harvest (Table 4-22) increased with increases in N rate in all tests except in 1983 at Gainesville. In 1983 at Hastings, total biomass at harvest

Table 4-20. Effects of N rate and amendment on plant shoot biomass at harvest in 1983 and 1984.

Treatment	Gainesville 1983	Gainesville 1984	Hastings 1983	Hastings 1984
	t/ha			
N Rate (kg/ha)				
67	–[†]	0.88	–	1.12
134	0.89(23)[‡]	1.19	0.65	0.81
202	1.08(22)	1.41	0.81	0.71
	*	L***	***	L***
Amendment				
Control	0.89(8)	1.09	0.64	0.89
5.6 kg/ha DCD	0.99(8)	1.17	0.73	0.90
11.2 kg/ha DCD	0.86(7)	1.15	0.75	0.83
0.56 kg/ha Nty[§]	1.08(7)	1.15	0.75	0.83
1.12 kg/ha Nty	1.01(8)	1.09	0.81	0.86
IBDU (1/3 of N)	1.08(6)	1.26	0.76	0.86
Significance				
DCD Linear	NS	NS	NS	NS
DCD Quadratic	NS	NS	NS	NS
Nty Rate	NS	NS	NS	NS
DCD v Nty	NS	NS	NS	NS
IBDU v Ih[¶]	NS	NS	NS	NS
Interactions	NS	Nty R X NR L *	NS	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

[†]Rate not included in 1983.
[‡]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[§]Nty = nitrapyrin.
[¶]Ih = inhibitors.

Table 4-21. Interaction (Nty R X NR L *) of nitrapyrin and N rate effects on plant shoot biomass at harvest (Gainesville, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	t/ha	
67	0.80	0.94 NS
134	1.25	1.17 NS
202	1.55	1.16 **
	L**	Lx

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.01 (**) probability levels, respectively.

Table 4-22. Effects of N rate and amendment on total biomass at harvest in 1983 and 1984.

	Gainesville		Hastings	
Treatment	1983	1984	1983	1984
	t/ha			
N Rate (kg/ha)				
67	–[†]	6.50	–	4.90
134	7.53(22)[‡]	7.87	4.86	5.61
202	7.99(21)	7.93	5.80	6.16
	NS	L***	***	L***
		Q*		
Amendment				
Control	7.92(8)	7.80	4.76	5.54
5.6 kg/ha DCD	7.58(7)	7.80	5.46	5.79
11.2 kg/ha DCD	7.40(7)	7.51	5.63	5.63
0.56 kg/ha Nty[§]	7.77(8)	7.12	4.80	5.33
1.12 kg/ha Nty	7.61(8)	6.96	5.78	5.41
IBDU (1/3 of N)	8.28(5)	7.41	5.54	5.63
Significance				
DCD Linear	NS	NS	*	NS
DCD Quadratic	NS	NS	NS	NS
Nty Rate	NS	NS	*	NS
DCD v Nty	NS	*	NS	x
IBDU v Ih[¶]	NS	NS	NS	NS
Interactions	NS	Nty R X NR L *	DCD Q X NR **	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

[†]Rate not included in 1983.
[‡]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[§]Nty = nitrapyrin.
[¶]Ih = inhibitors.

increased from 4.86 to 5.80 t ha^{-1} with an increase in N rate from 134 to 202 kg ha^{-1}. In 1984 at Hastings, total biomass increased from 4.90 to 6.16 t ha^{-1} with an increase in N rate from 67 to 202 kg ha^{-1}. In 1984 at Gainesville, total biomass increased from 6.50 to 7.87 t ha^{-1} with an increase in N rate from 67 to 134 kg ha^{-1}. A further increase in N rate to 202 kg ha^{-1} did not influence total biomass at harvest.

Amendment effects. In 1983 at Hastings, DCD rate interacted with N rate effects on total biomass (Table 4-23). With 134 kg ha^{-1} N, total biomass increased from 3.75 to 5.66 t ha^{-1} with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. A further increase in DCD rate did not influence total biomass. With 202 kg ha^{-1} N, DCD rate did not influence total biomass at harvest.

In 1983 at Hastings, total biomass at harvest increased from 4.80 to 5.78 t ha^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1} (Table 4-22). In 1984 at Gainesville, nitrapyrin rate interacted with N rate effects on total biomass at harvest (Table 4-24). With 67 kg ha^{-1} N, total biomass increased from 5.62 to 7.13 t ha^{-1} with an increase in nitrapyrin rate. With 134 and 202 kg ha^{-1} N, nitrapyrin rate had no effect on total biomass.

In 1984 at both locations, the DCD treatments resulted in higher total biomass at harvest than did the nitrapyrin treatments (Table 4-22). At Gainesville, total biomass

Table 4-23. Interaction (DCD Q X NR **) of DCD and N rate effects on total biomass at harvest (Hastings, 1983).

	DCD Rate (kg/ha)		
N Rate	0	5.6	11.2
kg/ha	t/ha		
134	3.75	5.66	5.01 L*Q**
202	5.77	5.27	6.26 NS
	*	NS	NS

Nonsignificant (NS) or significant at the 0.05 (*) or 0.01 (**) probability levels, respectively.

Table 4-24. Interaction (Nty R X NR L *) of nitrapyrin rate and N rate effects on total biomass at harvest (Gainesville, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	t/ha	
67	5.62	7.13 *
134	7.91	7.01 NS
202	7.84	6.74 NS
	L**	NS
	Qx	

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), or 0.01 (**) probability levels, respectively.

means were 7.66 t ha^{-1} with DCD and 7.04 t ha^{-1} with nitrapyrin. At Hastings, total biomass means were 5.71 t ha^{-1} with DCD and 5.37 t ha^{-1} with nitrapyrin.

Plant Shoot N Concentration at Harvest

N effects. In 1983 at Gainesville, plant shoot N concentration at harvest (Table 4-25) increased from 2.04 to 2.34% with an increase in N rate from 134 to 202 kg ha^{-1}. In 1984, shoot N concentration increased from 2.16 to 3.38% at Gainesville, and from 1.40 to 2.02% at Hastings, with an increase in N rate from 67 to 202 kg ha^{-1}.

Amendment effects. In 1984 at Hastings, DCD and N rate interacted in their effects on plant shoot N concentration at harvest (Table 4-26). With 67 kg ha^{-1} N, shoot N concentration decreased from 1.52 to 1.38% with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. With a further increase in DCD to 11.2 kg ha^{-1}, shoot N concentration was not affected. With 134 and 202 kg ha^{-1} N, plant shoot N concentration at was not affected by DCD rate.

In 1984 at Hastings, plant shoot N concentration at harvest was influenced by an interaction between nitrapyrin and N rate effects (Table 4-27). With 202 kg ha^{-1} N, shoot N concentration increased from 1.83 to 2.07% with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 67 and 134 kg ha^{-1} N, plant shoot N concentration was not affected by nitrapyrin rate.

Table 4-25. Effects of N rate and amendment on plant shoot N concentration at harvest in 1983 and 1984.

Treatment	Gainesville 1983	Gainesville 1984	Hastings 1983	Hastings 1984
	% N			
N Rate (kg/ha)				
67	-[†]	2.16	-	1.40
134	2.04(23)[‡]	2.64	2.47	1.71
202	2.34(22)	3.38	2.56	2.02
	L**	L***	NS	L***
Amendment				
Control	2.06(8)	2.98	2.47	1.70
5.6 kg/ha DCD	2.24(8)	2.81	2.56	1.71
11.2 kg/ha DCD	2.05(7)	3.17	2.52	1.69
0.56 kg/ha Nty[§]	2.13(8)	2.90	2.57	1.66
1.12 kg/ha Nty	2.19(8)	2.79	2.54	1.72
IBDU (1/3 of N)	2.48(6)	2.96	2.41	1.79
Significance				
DCD Linear	NS	NS	NS	NS
DCD Quadratic	NS	NS	NS	NS
Nty Rate	NS	NS	NS	NS
DCD v Nty	NS	NS	NS	NS
IBDU v Ih[¶]	*	NS	NS	x
Interactions	NS	NS	N	DCD Q X NR L x Nty R X NR L * IBDU v Ih X NR L **

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

[†]Rate not included in 1983.
[‡]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[§]Nty = nitrapyrin.
[¶]Ih = inhibitors.

Table 4-26. Interaction (DCD Q X NR L x) of DCD and N rate effects on plant N concentration at harvest (Hastings, 1984).

	DCD Rate (kg/ha)		
N Rate	0	5.6	11.2
kg/ha	% N		
67	1.52	1.38	1.40 L*Qx
134	1.60	1.65	1.71 NS
202	1.96	2.10	1.95 NS
	L*** Q**	L***	L***

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table 4-27. Interaction (Nty R X NR L *) of nitrapyrin and N rate effects on plant shoot N concentration at harvest (Hastings, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	% N	
67	1.43	1.37 NS
134	1.73	1.71 NS
202	1.83	2.07 x
	L***	L***

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

In 1983 at Gainesville, plant shoot N concentration means were higher with the IBDU treatment (2.48%) than with the inhibitor treatments (2.15%). In 1984 at Hastings, the IBDU v inhibitor contrast interacted with N rate effects on shoot N concentration (Table 4-28). The trend in the data reversed as N rate increased. With 67 kg ha^{-1} N, shoot N concentration means were higher with inhibitors (1.40%) than with IBDU (1.29%). With 202 kg ha^{-1} N, however, shoot N concentration means were higher with IBDU (2.23%) than with inhibitors (1.99%). With 134 kg ha^{-1} N, plant shoot N concentration means were similar with the two amendment types.

N Uptake by Plant Shoots at Harvest

N Effects. In 1983 the amount of N uptake by plant shoots at harvest (Table 4-29) increased from 18.3 to 25.6 kg ha^{-1} at Gainesville, and from 16.3 to 20.7 kg ha^{-1} at Hastings, with an increase in N rate from 134 to 202 kg ha^{-1}. In 1984 at Gainesville, an increase in N rate from 67 to 202 kg ha^{-1} resulted in an increase in shoot N uptake from 19.0 to 47.8 kg ha^{-1}, while at Hastings, there was no N rate effect.

Amendment effects. In 1984 at Gainesville, nitrapyrin and N rate effects interacted in their effects on shoot N uptake (Table 4-30). With 202 kg ha^{-1} N, shoot N uptake decreased from 54.1 to 36.0 kg ha^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 67 and 134 kg ha^{-1} N, nitrapyrin rate had no effect on shoot N uptake.

Table 4-28. Interaction (IBDU v Ih X NR L **) of IBDU v inhibitors, and N rate effects on plant shoot N concentration at harvest (Hastings, 1984).

N Rate	IBDU	Inhibitors
kg/ha	% N	
67	1.29	1.40 **
134	1.83	1.70 NS
202	2.23	1.99 *
	L***	L***

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table 4-29. Effects of N rate and amendment on N uptake by plant shoots at harvest in 1983 and 1984.

Treatment	Gainesville 1983	Gainesville 1984	Hastings 1983	Hastings 1984
	kg/ha			
N Rate (kg/ha)				
67	-[†]	19.0	-	15.7
134	18.3(23)[‡]	32.0	16.3	14.1
202	25.6(22)	47.8	20.7	15.0
	L**	L***	L**	NS
Amendment				
Control	18.2(8)	30.4	16.2	14.8
5.6 kg/ha DCD	22.6(8)	31.8	19.1	15.2
11.2 kg/ha DCD	17.6(7)	34.8	18.9	13.2
0.56 kg/ha Nty[§]	24.0(8)	34.7	18.9	13.2
1.12 kg/ha Nty	22.4(8)	29.3	20.4	14.6
IBDU (1/3 of N)	26.8(6)	36.8	18.5	15.5
Significance				
DCD Linear	NS	NS	NS	NS
DCD Quadratic	NS	NS	NS	NS
Nty Rate	NS	NS	NS	NS
DCD v Nty	NS	NS	NS	NS
IBDU v Ih[¶]	NS	NS	NS	NS
Interactions	DCD v Nty X NR x	Nty R X NR L *	NS	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

[†]Rate not included in 1983.
[‡]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[§]Nty = nitrapyrin.
[¶]Ih = inhibitors.

Table 4-30. Interaction (Nty R X NR L *) of nitrapyrin and N rate effects on N uptake by plant shoots at harvest (Gainesville, 1984).

N Rate	Nitrapyrin Rate (kg/ha)		
	0.56	1.12	
kg/ha	kg/ha		
67	18.0	19.9	NS
134	32.1	32.0	NS
202	54.1	36.0	***
	L**	Lx	

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table 4-31. Interaction (DCD v nitrapyrin X NR x) of DCD v nitrapyrin, and N rate effects on N uptake by plant shoots at harvest (Gainesville, 1983).

N Rate	DCD	Nitrapyrin
kg/ha	kg/ha	
134	17.9	16.2 NS
202	22.4	30.3 NS
	NS	L**

Nonsignificant (NS) or significant at the 0.10 (x) or 0.01 (**) probability levels, respectively.

In 1983 at Gainesville, the DCD v nitrapyrin contrast interacted with N rate effects on shoot N uptake means (Table 4-31). Shoot N uptake was influenced by N rate with the nitrapyrin treatments but not with the DCD treatments. With nitrapyrin, shoot N uptake increased from 16.2 to 30.3 kg ha^{-1} with an increase in N rate from 134 to 202 kg ha^{-1}.

N Uptake by Tubers

N effects. The amount of N uptake by tubers (Table 4-32) increased with increases in N rate in both years at both locations. In 1983, tuber N uptake increased from 65.8 to 74.7 kg ha^{-1} at Gainesville, and from 41.3 to 53.7 kg ha^{-1} at Hastings, with an increase in N rate from 134 to 202 kg ha^{-1}. In 1984 at Gainesville, tuber N uptake increased from 69.2 to 96.8 kg ha^{-1} with an increase in N rate from 67 to 134 kg ha^{-1}. Tuber N uptake was not influenced by a further increase in N rate to 202 kg ha^{-1}. In 1984 at Hastings, tuber N uptake increased from 42.1 to 72.4 kg ha^{-1} with an increase in N rate from 67 to 202 kg ha^{-1}.

Amendment effects. In 1983 at Hastings, DCD rate interacted with N rate effects on tuber N uptake (Table 4-33). With 134 kg ha^{-1} N, tuber N uptake increased from 30.1 to 50.3 kg ha^{-1} with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. A further increase in DCD rate to 11.2 kg ha^{-1} resulted in a reduction of tuber N uptake to 43.2 kg ha^{-1}, which was higher than tuber N uptake with 0 DCD. With 202 kg ha^{-1} N, DCD rate had no effect on tuber N uptake.

Table 4-32. Effects of N rate and amendment on N uptake by tubers in 1983 and 1984.

	Gainesville		Hastings	
Treatment	1983	1984	1983	1984
	kg/ha			
N Rate (kg/ha)				
67	-[†]	69.2	-	42.1
134	65.8(22)[‡]	96.8	41.3	58.2
202	74.7(21)	104.8	53.7	72.4
	L*	L***	L***	L***
		Q*		
Amendment				
Control	68.1(8)	94.2	41.4	57.1
5.6 kg/ha DCD	67.7(7)	96.1	47.8	59.2
11.2 kg/ha DCD	65.5(7)	91.6	52.0	60.7
0.56 kg/ha Nty[§]	69.1(8)	85.2	39.7	54.1
1.12 kg/ha Nty	70.4(8)	84.5	55.5	55.3
IBDU (1/3 of N)	80.8(5)	90.0	48.5	59.0
Significance				
DCD Linear	NS	NS	*	NS
DCD Quadratic	NS	NS	NS	NS
Nty Rate	NS	NS	***	NS
DCD v Nty	NS	x	NS	x
IBDU v Ih[¶]	*	NS	NS	NS
Interactions	NS	Nty R X NR L *	DCD Q X NR ** DCD v Nty X NR x	DCD v Nty X NR L x

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

[†]Rate not included in 1983.
[‡]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[§]Nty = nitrapyrin.
[¶]Ih = inhibitors.

Table 4-33. Interaction (DCD Q X NR **) of DCD and N rate effects on N uptake by tubers (Hastings, 1983).

	DCD Rate (kg/ha)		
N Rate	0	5.6	11.2
kg/ha	kg/ha		
134	30.1	50.3	43.2 L**Q***
202	52.8	45.3	60.7 NS
	x	NS	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table 4-34. Interaction (Nty R X NR L *) of nitrapyrin and N rate effects on N uptake by tubers (Gainesville, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	kg/ha	
67	57.2	77.5 x
134	95.8	88.2 NS
202	102.8	87.9 NS
	L***	NS
	Q*	

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

In 1983 at Hastings, tuber N uptake increased from 39.7 to 55.5 kg ha^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1} (Table 4-32). In 1984 at Gainesville, nitrapyrin and N rate interacted in their effects on tuber N uptake (Table 4-34). With 67 kg ha^{-1} N, tuber N uptake increased from 57.2 to 77.5 kg ha^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 134 and 202 kg ha^{-1} N, tuber N uptake was not affected by nitrapyrin rate.

In 1983 at Hastings, the DCD v nitrapyrin contrast interacted with N rate effects on tuber N uptake (Table 4-35). With 134 kg ha^{-1} N, tuber N uptake means were greater with DCD (46.8 kg ha^{-1}) than with nitrapyrin (38.9 kg ha^{-1}). With 202 kg ha^{-1} N, tuber N uptake means were similar with the two inhibitors.

In 1984 at both locations, tuber N uptake means were higher with DCD than with nitrapyrin. At Gainesville, tuber N uptake means were 93.8 kg ha^{-1} with DCD and 84.8 kg ha^{-1} with nitrapyrin. In 1984 at Hastings, the DCD v nitrapyrin contrast interacted with N rate effects on tuber N uptake (Table 4-36). With 202 kg ha^{-1} N, tuber N uptake means were higher with DCD (79.9 kg ha^{-1}) than with nitrapyrin (65.9 kg ha^{-1} N). With 67 and 134 kg ha^{-1} N, tuber N uptake means were similar with the two inhibitors. In 1983 at Gainesville, tuber N uptake means were higher with IBDU (80.8 kg ha^{-1}) than with inhibitors (68.2 kg ha^{-1} N) (Table 4-32).

Table 4-35. Interaction (DCD v nitrapyrin X NR x) of DCD v nitrapyrin, and N rate effects on N uptake by tubers (Hastings, 1983).

N Rate	DCD	Nitrapyrin	
kg/ha	----------kg/ha----------		
134	46.8	38.9	**
202	53.0	56.3	NS
	NS	*	

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.01 (**) probability levels, respectively.

Table 4-36. Interaction (DCD v nitrapyrin X NR L x) of DCD v nitrapyrin, and N rate effects on N uptake by tubers (Hastings, 1984).

N Rate	DCD	Nitrapyrin	
kg/ha	----------kg/ha----------		
67	41.9	39.8	NS
134	58.2	58.5	NS
202	79.9	65.9	**
	L***	L***	

Nonsignificant (NS) or significant at the 0.1 (x), 0.01 (**), or 0.001 (***) probability levels, respectively.

Total N Uptake by Plant Shoots and Tubers

N effects. Total N uptake by plant shoots and tubers (Table 4-37) increased with increases in N rate in all tests. In 1983, with an increase in N rate from 134 to 202 kg ha^{-1}, total N uptake increased from 83.8 to 100.3 kg ha^{-1} at Gainesville, and from 57.6 to 74.4 kg ha^{-1} at Hastings. In 1984 at Gainesville, total N uptake increased from 88.2 to 128.8 kg ha^{-1} with an increase in N rate from 67 to 134 kg ha^{-1}. A further increase in N rate to 202 kg ha^{-1} did not influence total N uptake. In 1984 at Hastings, total N uptake increased from 57.7 to 87.5 kg ha^{-1} with an increase in N rate from 67 to 202 kg ha^{-1}.

Amendment effects. In 1983 at Hastings, DCD rate interacted with N rate effects on total N uptake (Table 4-38). With 134 kg ha^{-1} N, total N uptake increased from 42.4 to 68.6 kg ha^{-1} with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. A further increase in DCD to 11.2 kg ha^{-1} did not influence total N uptake. In 1983 at Hastings, with 202 kg ha^{-1} N, total N uptake was not influenced by DCD rate.

In 1983 at Hastings, total N uptake by plant shoots and tubers increased from 57.6 to 75.9 kg ha^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. In 1984 at Gainesville, nitrapyrin and N rate interacted in their effects on total N uptake (Table 4-39). With 67 kg ha^{-1} N, total N uptake increased from 75.3 to 97.4 kg ha^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg

Table 4-37. Effects of N rate and amendment on total N uptake by plant shoots and tubers at harvest in 1983 and 1984.

	Gainesville		Hastings	
Treatment	1983	1984	1983	1984
	kg/ha			
N Rate (kg/ha)				
67	-[†]	88.2	-	57.7
134	83.3(22)[‡]	128.8	57.6	72.3
202	100.3(21)	152.6	74.4	87.5
	**	L*** Q*	***	L***
Amendment				
Control	86.2(8)	124.6	57.6	72.0
5.6 kg/ha DCD	89.2(7)	128.0	67.0	74.4
11.2 kg/ha DCD	83.1(7)	126.4	70.9	73.9
0.56 kg/ha Nty[§]	93.1(8)	120.0	57.6	70.5
1.12 kg/ha Nty	92.9(8)	113.8	75.9	69.9
IBDU (1/3 of N)	107.7(5)	126.7	67.0	74.4
Significance				
DCD Linear	NS	NS	*	NS
DCD Quadratic	NS	NS	NS	NS
Nty Rate	NS	NS	**	NS
DCD v Nty	NS	*	NS	NS
IBDU v Ih[¶]	*	NS	NS	NS
Interactions	NS	Nty R X NR Q **	DCD Q X NR **	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

†Rate not included in 1983.
‡Gainesville 1983 means are least square means. Number of observations are in parentheses.
§Nty = nitrapyrin.
¶Ih = inhibitors.

Table 4-38. Interaction (DCD Q X NR **) of DCD and N rate effects on total N uptake by plant shoots and tubers at harvest (Hastings, 1983).

	DCD Rate (kg/ha)			
N Rate	0	5.6	11.2	
kg/ha	kg/ha			
134	42.4	68.6	59.9	L*Q**
202	72.8	65.3	81.9	NS
	x	NS	NS	

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.01 (**) probability levels, respectively.

Table 4-39. Interaction (Nty R X NR Q **) of nitrapyrin and N rate effects on total N uptake by plant shoots and tubers at harvest (Gainesville, 1984).

	Nitrapyrin Rate (kg/ha)		
N Rate	0.56	1.12	
kg/ha	kg/ha		
67	75.3	97.4	x
134	127.9	120.0	NS
202	156.8	123.9	x
	L***	NS	

Nonsignificant (NS) or significant at the 0.10 (x), 0.01 (**), or 0.001 (***) probability levels, respectively.

ha^{-1}. With 202 kg ha^{-1} N, however, total N uptake decreased from 156.8 to 123.9 kg ha^{-1} with an increase in nitrapyrin rate. With 134 kg ha^{-1} N, total N uptake was not influenced by nitrapyrin rate.

In 1984 at Gainesville, total N uptake means were greater with DCD (127.2 kg ha^{-1}) than with nitrapyrin (116.9 kg ha^{-1}) (Table 4-37). In 1983 at Gainesville, total N uptake means were higher with IBDU (107.7 kg ha^{-1}) than with inhibitors (89.6 kg ha^{-1}).

Leaf N Concentration at Tuber Initiation

N effects. In 1983 at Hastings, concentration of leaf N at tuber initiation (LNTI) (Table 4-40) increased from 3.57 to 3.75% with an increase in N rate from 134 to 202 kg ha^{-1}. In 1984 at Hastings, LNTI concentration increased from 5.01 to 5.55% with an increase in N rate from 67 to 202 kg ha^{-1}. In 1985 at Hastings, LNTI concentration increased from 5.62 to 6.17% with an increase in N rate from 67 to 134 kg ha^{-1}. A further increase in N to 202 kg ha^{-1} did not influence LNTI concentration. Leaf N concentration at tuber initiation was not influenced by N rate in 1983 or 1984 at Gainesville.

Amendment effects. In 1983 at Hastings, LNTI concentration increased from 3.45 to 3.86% with an increase in DCD rate from 0 to 11.2 kg ha^{-1} (Table 4-40). In 1984 at Gainesville, LNTI concentration decreased from 4.87 to 4.65% with an increase in DCD rate from 0 to 11.2 kg ha^{-1}. In the

Table 4-40. Effects of N rate and amendment on leaf N concentration at tuber initiation.

Treatment	Gainesville 1983[43][†]	Gainesville 1984[48]
	% N	
N Rate (kg/ha)		
67	–[‡]	4.76
134	5.65(23)[§]	4.87
202	5.76(22)	4.80
	NS	NS
Amendment		
Control	5.70(8)	4.87
5.6 kg/ha DCD	5.68(8)	4.83
11.2 kg/ha DCD	5.76(7)	4.65
0.56 kg/ha Nty[¶]	5.61(8)	4.86
1.12 kg/ha Nty	5.75(8)	4.73
IBDU (1/3 of N)	5.73(6)	4.92
Significance		
DCD Linear	NS	*
DCD Quadratic	NS	NS
Nty Rate	NS	NS
DCD v Nty	NS	NS
IBDU v Ih[#]	NS	*
Interactions	NS	Nty R X NR Q *

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[†]Numbers in brackets represent days after planting.
[‡]Rate not included in 1983.
[§]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[¶]Nty = nitrapyrin.
[#]Ih = inhibitors.

Table 4-40.--Extended

Hastings		
1983[54]	1984[55]	1985[51]
% N		
-	5.01	5.62
3.57	5.22	6.17
3.75	5.55	6.40
**	L***	L***
		Q**
3.45	5.20	6.09
3.62	5.20	6.06
3.86	5.37	6.17
3.61	5.22	6.15
3.85	5.25	6.03
3.58	5.31	5.90
**	**	NS
NS	x	NS
*	NS	NS
NS	NS	NS
x	NS	**
Nty R X NR x	IBDU v Ih X NR L ***	DCD v Nty X NR Q *
DCD v Nty X NR x		

same year at Hastings, LNTI concentration was not influenced by an increase in DCD rate from 0 to 5.6 kg ha^{-1}. A further increase in DCD to 11.2 kg ha^{-1}, resulted in an increase in LNTI concentration from 5.20 to 5.37%. Leaf N concentration at tuber initiation was not influenced by DCD rate in 1983 at Gainesville or in 1985 at Hastings.

In 1983 at Hastings, LNTI concentration increased from 3.61 to 3.85% with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. In 1984 at Gainesville, nitrapyrin and N rate interacted in their effects on LNTI concentration (Table 4-41). With 67 kg ha^{-1} N, LNTI concentration decreased from 4.90 to 4.69% with an increase in nitrapyrin rate. With 134 and 202 kg ha^{-1} N, nitrapyrin rate had no effect on LNTI concentration.

In 1985 at Hastings, the DCD v nitrapyrin contrast interacted with N rate effects on LNTI concentration (Table 4-42). With 134 kg ha^{-1} N, LNTI concentration means were higher with DCD (6.32%) than with nitrapyrin (6.08%). With 67 and 202 kg ha^{-1} N, LNTI concentration means were similar with the two inhibitors.

Leaf N concentration at tuber initiation was higher with IBDU (4.92%) than with inhibitors (4.77%) in 1984 at Gainesville (Table 4-40). In 1983 at Hastings, IBDU resulted in lower LNTI concentration means (3.58%) than did inhibitors (3.74%). In 1984 at Hastings, the IBDU v inhibitors contrast interacted with N rate (Table 4-43). With 67

Table 4-41. Interaction (Nty R X NR *) of nitrapyrin rate and N rate effects on leaf N concentration at tuber initiation (48 dap) (Gainesville, 1984).

N Rate	Nitrapyrin Rate (kg/ha) 0.56	1.12
kg/ha	% N	
67	4.90	4.69 x
134	4.76	4.86 NS
202	4.94	4.64 NS
	NS	NS

Nonsignificant (NS) or significant at the 0.10 (x) or 0.05 (*), probability levels, respectively.

Table 4-42. Interaction (DCD v nitrapyrin X NR Q *) of DCD v nitrapyrin, and N rate effects on leaf N concentration at tuber initiation (51 dap) (Hastings, 1985).

N Rate	DCD	Nitrapyrin
kg/ha	% N	
67	5.62	5.70 NS
134	6.32	6.08 *
202	6.40	6.49 NS
	L***	L***
	Q***	

Nonsignificant (NS) or significant at the 0.05 (*) or 0.001 (***) probability levels, respectively.

Table 4-43. Interaction (IBDU v Ih X NR L ***) of IBDU v inhibitors, and N rate effects on leaf N concentration at tuber initiation (55 dap) (Hastings, 1984).

N Rate	IBDU	Inhibitors
kg/ha	—— % N ——	
67	5.23	4.96 ***
134	5.31	5.22 NS
202	5.40	5.60 **
	Lx	L***

Nonsignificant (NS) or significant at the 0.10 (x), 0.01 (**), or 0.001 (***) probability levels, respectively.

kg ha^{-1} N, LNTI concentration means were higher with IBDU (5.23%) than with inhibitors (4.96%). With 202 kg ha^{-1} N, LNTI concentration means were higher with inhibitors (5.60%) than with IBDU (5.40%). With 134 kg ha^{-1} N, LNTI concentration means were similar with the two types of amendments.

Leaf N Concentration at Flowering

N effects. In 1983 at Gainesville, leaf N concentration at the flowering or tuber bulking stage (LNF) increased from 3.92 to 4.22% with an increase in N rate from 134 to 202 kg ha^{-1} (Table 4-44). In 1984, LNF concentration increased from 3.75 to 4.65% at Gainesville, and from 2.88 to 3.80% at Hastings, with an increase in N rate from 67 to 202 kg ha^{-1}. In 1985 at Hastings, LNF concentration increased from 3.50 to 5.13% with an increase in N rate from 67 to 202 kg ha^{-1}.

Amendment effects. Leaf N concentration at flowering increased with an increase in DCD rate in three of four year-location combinations. Increasing DCD rate resulted in an increase in leaf N concentration at flowering from 3.84 to 4.12% in 1983 at Gainesville, from 4.13 to 4.28% in 1984 at Gainesville, and from 4.28 to 4.42% in 1985 at Hastings. In 1984 at Hastings, DCD rate interacted with N rate effects on LNF concentration (Table 4-45). With 202 kg ha^{-1} N, LNF concentration was not affected by an increase in DCD rate from 0 to 5.6 kg ha^{-1}, but with a further increase in DCD to 11.2 kg ha^{-1}, LNF concentration decreased from 3.95 to

Table 4-44. Effects of N rate and amendment on leaf N concentration at flowering.

	Gainesville	
Treatment	1983[66][†]	1984[74]
	% N	
N Rate (kg/ha)		
67	–[‡]	3.75
134	3.92(23)[§]	4.18
202	4.22(22)	4.65
	**	L***
Amendment		
Control	3.84(8)	4.13
5.6 kg/ha DCD	3.78(8)	4.16
11.2 kg/ha DCD	4.12(7)	4.28
0.56 kg/ha Nty[¶]	4.05(8)	4.21
1.12 kg/ha Nty	4.11(8)	4.16
IBDU (1/3 of N)	4.47(6)	4.21
Significance		
DCD Linear	x	*
DCD Quadratic	NS	NS
Nty Rate	NS	NS
DCD v Nty	NS	NS
IBDU v Ih[#]	**	NS
Interactions	IBDU v Ih X NR *	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[†]Numbers in brackets represent days after planting.
[‡]Rate not included in 1983.
[§]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[¶]Nty = nitrapyrin.
[#]Ih = inhibitors.

Table 4-44--Extended.

Hastings	
1984[81]	1985[73]
% N	
2.88	3.50
3.40	4.36
3.80	5.13
L***	L***
3.38	4.28
3.38	4.36
3.18	4.42
3.34	4.39
3.44	4.37
3.43	4.17
**	x
x	NS
NS	NS
*	NS
x	**
DCD Q X NR L *	IBDU v Ih X NR L *
Nty R X NR Q x	
DCD v Nty X NR Q **	
IBDU v Ih X NR Q *	

Table 4-45. Interaction (DCD Q X NR L *) of DCD and N rate effects on leaf N concentration at flowering (81 dap) (Hastings, 1984).

	DCD Rate (kg/ha)		
N Rate	0	5.6	11.2
kg/ha	% N		
67	2.91	2.80	2.84 NS
134	3.37	3.40	3.15 NS
202	3.87	3.95	3.55 L**Q**
	L***	L***	L***

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table 4-46. Interaction (Nty R X NR Q *) of nitrapyrin and N rate effects on leaf N concentration at flowering (81 dap) (Hastings, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	% N	
67	2.83	2.94 x
134	3.62	3.53 NS
202	3.58	3.86 **
	L*** Q***	L***

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

3.55%. With 67 and 134 kg ha^{-1} N, DCD rate had no effect on LNF concentration.

In 1984 at Hastings, nitrapyrin rate interacted with N rate effects on LNF concentration (Table 4-46). With 67 kg ha^{-1} N, LNF concentration increased from 2.83 to 2.94%, and with the 202 kg ha^{-1} N, LNF concentration increased from 3.58 to 3.86% with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 134 kg ha^{-1} N, nitrapyrin rate had no effect on LNF concentration. In 1983 and 1984 at Gainesville, and in 1985 at Hastings, LNF concentration was not influenced by nitrapyrin rate.

In 1984 at Hastings, the DCD v nitrapyrin contrast interacted with N rate effects on LNF concentration (Table 4-47). With 134 kg ha^{-1} N, LNF concentration means were higher with nitrapyrin (3.57%) than with DCD (3.27%). With 67 and 202 kg ha^{-1} N, LNF concentration means were similar with the two inhibitors.

In 1983 at Gainesville, the IBDU v inhibitors contrast interacted with N rate effects on LNF concentration (Table 4-48). With 134 kg ha^{-1} N, LNF concentration means were higher with IBDU (4.54%) than with inhibitors (3.80%). With 202 kg ha^{-1} N, LNF concentration means were similar with the two types of amendments.

In 1984 at Hastings, the IBDU v inhibitors contrast interacted with N rate effects on LNF concentration (Table 4-49). With 67 kg ha^{-1} N, LNF concentration means were

Table 4-47. Interaction (DCD v nitrapyrin X NR Q **) of DCD v nitrapyrin, and N rate effects on leaf N concentration at flowering (81 dap) (Hastings, 1984).

N Rate	DCD	Nitrapyrin
kg/ha	——————% N——————	
67	2.82	2.89 NS
134	3.27	3.57 **
202	3.75	3.72 NS
	L***	L***
	Q**	

Nonsignificant (NS) or significant at the 0.01 (**) or 0.001 (***) probability levels, respectively.

Table 4-48. Interaction (IBDU v Ih X NR *) of IBDU v inhibitors, and N rate effects on leaf N concentration at flowering (66 dap) (Gainesville, 1983).

N Rate	IBDU	Inhibitors
kg/ha	——————% N——————	
134	4.54	3.80 **
202	4.41	4.24 NS
	NS	NS**

Nonsignificant (NS) or significant at the 0.05 (*) or 0.01 (**) probability levels, respectively.

Table 4-49. Interaction (IBDU v Ih X NR Q *) of IBDU v inhibitors, and N rate effects on leaf N concentration at flowering (81 dap) (Hastings, 1984).

N Rate	IBDU	Inhibitors
kg/ha	% N	
67	2.98	2.85 *
134	3.34	3.42 NS
202	3.98	3.74 **
	L***	L***
	Q**	Q*

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table 4-50. Interaction (IBDU v IH X NR L *) of IBDU v inhibitors, and N rate effects on leaf N concentration at flowering (73 dap) (Hastings, 1985).

N Rate	IBDU	Inhibitors
kg/ha	% N	
67	3.47	3.51 NS
134	4.25	4.43 *
202	4.80	5.22 **
	L***	L***
	Qx	

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

higher with IBDU (2.98%) than with inhibitors (2.85%). With 202 kg ha^{-1} N rate as well, LNF concentration means were higher with IBDU (3.98%) than with inhibitors (3.74%). With 134 kg ha^{-1} N, LNF concentration means were similar with the two types of amendment.

In 1985 at Hastings, LNF concentration means were lower with the IBDU treatment than with the inhibitor treatments with the 134 and 202 kg ha^{-1} N rates (Table 4-50). With 134 kg ha^{-1} N, LNF concentration means were 4.25% with IBDU and 4.43% with inhibitors. With 202 kg ha^{-1} N, LNF concentration means were 4.80% with IBDU and 5.22% with inhibitors. With 67 kg ha^{-1} N, LNF concentration means were similar with the two types of amendment.

Leaf N Concentration at Tuber Maturation

N effects. Concentration of leaf N at tuber maturation (LNTM) increased with increases in N rate in all years and locations years where LNTM was measured (Table 4-51). In 1983, LNTM concentration increased from 2.69 to 2.91% at Gainesville, and from 2.85 to 3.11% at Hastings, with an increase in N rate from 134 to 202 kg ha^{-1}. In 1984 at Gainesville, an increase in N rate from 67 to 134 kg ha^{-1} did not influence LNTM concentration. With an increase in N rate from 134 to 202 kg ha^{-1}, however, LNTM concentration increased from 3.13 to 3.80%. In 1984 at Hastings, an increase in N rate from 67 to 134 kg ha^{-1} did not influence LNTM concentration. With an increase in N rate from 134 to

Table 4-51. Effects of N rate and amendment on leaf N concentration at tuber maturation in 1983 and 1984.

Treatment	Gainesville		Hastings	
	1983[93][†]	1984[94]	1983[95]	1984[98]
	% N			
N Rate (kg/ha)				
67	-[‡]	2.98	-	2.19
134	2.69(23)[§]	3.13	2.85	2.37
202	2.91(22)	3.80	3.11	2.68
	*	L***	**	L***
		Q***		Q*
Amendment				
Control	2.74(8)	3.31	3.04	2.45
5.6 kg/ha DCD	2.84(8)	3.18	2.87	2.42
11.2 kg/ha DCD	2.79(7)	3.38	3.16	2.37
0.56 kg/ha Nty[¶]	2.59(8)	3.28	2.94	2.37
1.12 kg/ha Nty	2.83(8)	3.26	3.03	2.41
IBDU (1/3 of N)	2.98(6)	3.40	2.84	2.46
Significance				
DCD Linear	NS	NS	NS	NS
DCD Quadratic	NS	x	x	NS
Nty Rate	NS	NS	NS	NS
DCD v Nty	NS	NS	NS	NS
IBDU v Ih[#]	NS	NS	NS	NS
Interactions	NS	Nty R X NR Q *** DCD v Nty X NR Q *	NS	DCD Q X NR L *

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

[†]Numbers in brackets represent days after planting.
[‡]Rate not included in 1983.
[§]Gainesville 1983 means are least square means. Number of observations are in parentheses.
[¶]Nty = nitrapyrin.
[#]Ih = inhibitors.

202 kg ha^{-1}, however, LNTM concentration increased from 2.37 to 2.68%.

Amendment effects. In 1984 at Gainesville, LNTM concentration decreased from 3.31 to 3.18% with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. A further increase in DCD to 11.2 kg ha^{-1} increased LNTM to a concentration that was not different from that with 0 DCD. In 1983 at Hastings, LNTM concentration decreased from 3.04 to 2.87% with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. A further increase in DCD to 11.2 kg ha^{-1} increased LNTM to a concentration that was not different from that with 0 DCD.

In 1984 at Hastings, DCD and N rate interacted in their effects on LNTM concentration (Table 4-52). With 67 kg ha^{-1} N, LNTM concentration decreased from 2.26 to 2.12% with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. With a further increase in DCD to 11.2 kg ha^{-1}, LNTM increased to a concentration that was not different from that with 0 DCD. With 134 and 202 kg ha^{-1} N, LNTM concentration was not influenced by DCD rate.

In 1984 at Gainesville, nitrapyrin and N rate interacted in their effects on LNTM concentration (Table 4-53). With 67 kg ha^{-1} N, LNTM concentration increased from 2.78 to 3.15% with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 134 kg ha^{-1} N, however, LNTM concentration decreased from 3.30 to 2.68% with an increase in nitrapyrin

Table 4-52. Interaction (DCD L X NR L *) of DCD and N rate effects on leaf N concentration at tuber maturation (98 dap) (Hastings, 1984).

	DCD Rate (kg/ha)		
N Rate	0	5.6	11.2
kg/ha	% N		
67	2.26	2.12	2.29 Q*
134	2.40	2.44	2.24 NS
202	2.69	2.70	2.58 NS
	L***	L***	L***
			Q***

Nonsignificant (NS) or significant at the 0.05 (*) or 0.001 (***) probability levels, respectively.

Table 4-53. Interaction (Nty R X NR Q ***) of nitrapyrin rate and N rate effects on leaf N concentration at tuber maturation (94 dap) (Gainesville, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	% N	
67	2.78	3.15 **
134	3.30	2.68 ***
202	3.77	3.95 NS
	L***	L***
		Q***

Nonsignificant (NS) or significant at the 0.01 (**) or 0.001 (***) probability levels, respectively.

rate. With 202 kg ha^{-1} N, nitrapyrin rate had no effect on LNTM concentration.

In 1984 at Gainesville, the DCD v nitrapyrin contrast interacted with N rate effects on LNTM concentration (Table 4-54). With 134 kg ha^{-1} N, LNTM concentration means were higher with the DCD treatments (3.22%) than with the nitrapyrin treatments (2.99%). With 67 and 202 kg ha^{-1} N, LNTM concentration means were similar with the two inhibitors.

Table 4-54. Interaction (DCD v nitrapyrin X NR Q *) of DCD v nitrapyrin, and N rate effects on leaf N concentration at tuber maturation (94 dap) (Gainesville, 1984).

N Rate	DCD	Nitrapyrin
kg/ha	% N	
67	2.94	2.97 NS
134	3.22	2.99 x
202	3.68	3.86 NS
	L***	L***
		Q**

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

CHAPTER 5
EXTRACTABLE N AND DCD IN SOILS PLANTED TO POTATO

Soil Inorganic N

To be beneficial to crop growth and yield, nitrification inhibitors should inhibit nitrification, thereby increasing the supply of plant-available N in the soil rooting zone. Therefore, data in Chapter 5 are presented as total extractable soil inorganic N (SIN) concentration, e.g., NH_4^+-N plus NO_3^--N in the 0 to 30 cm depth rather than as NH_4^+-N and NO_3^--N separately. Soil inorganic N concentration data for six potato plant growth stages are shown in the tables in this chapter. Most treatment interactions shown in the main effect tables in this chapter were examined in detail in separate interaction tables. Some interactions were not presented in separate tables because they contributed no additional information about the data. Graphic depictions of SIN concentration with selected treatments are shown in Appendix C. Analysis of variance tables for extractable NH_4^+-N and NO_3^--N concentrations separately, and the ratio of NO_3^--N/(NO_3^--N + NH_4^+-N), are shown in Appendix D.

Fertilizer and amendment applications were carried out simultaneously with planting of the potato crops. Thus, the

days after fertilizer application referred to in this chapter, are equivalent to the days after planting referred to in Chapter 4.

Planting + one week. Soil samples were taken in the first week after planting at Hastings only. Samples were taken five and six days after fertilizer application in 1983 and 1984, respectively. In 1984 on day 6, SIN concentration increased from 77.4 to 193.9 mg kg^{-1} with an increase in N rate from 67 to 202 kg ha^{-1} (Table 5-1). In 1983 on day 5, SIN concentration was not influenced by N or DCD rate.

In 1984 on day 6 at Hastings, DCD rate interacted with N rate effects on SIN concentration (Table 5-2). With 67 kg ha^{-1} N, SIN concentration decreased from 83.2 to 63.7 mg kg^{-1} with an increase in DCD rate from 0 to 11.2 kg ha^{-1}. With 134 kg ha^{-1} N, DCD rate had no effect. With 202 kg ha^{-1} N, SIN concentration decreased from 202.0 to 147.6 mg kg^{-1} with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. With a further increase in DCD rate to 11.2 kg ha^{-1}, SIN concentration increased to 214.5 mg kg^{-1}, which was not different from the concentration with 0 DCD.

Soil was not sampled from the nitrapyrin or IBDU amended plots on day 5 in 1983. In 1984 on day 6, nitrapyrin rate interacted with N rate effects on SIN concentration (Table 5-3), with the nitrapyrin rate effect present only with 67 and 202 kg ha^{-1} N. With 67 kg ha^{-1} N, an

Table 5-1. Effects of N rate and amendment on soil inorganic N concentration at the planting + one week stage of potato (Hastings).

Independent Variable	1983[5][†]	1984[6]
	mg/kg N	
N Rate		
67 kg/ha	-[‡]	77.4
134 kg/ha	6.6	129.6
202 kg/ha	7.5	193.9
	NS	L***
DCD Rate		
0.0 kg/ha	6.0	137.1
5.6 kg/ha	8.0	120.0
11.2 kg/ha	7.1	132.3
	NS	NS
Nty[§] Rate		
0.56 kg/ha	-[¶]	137.6
1.12 kg/ha	-	160.7
		*
DCD v Nty	-	**
IBDU as 1/3 of N	-	114.0
IBDU v Ih[#]	-	**
Interactions		
DCD L X NR	NS	NS
DCD Q X NR	NS	L**
Nty R X NR	-	Q*
DCD v Nty X NR	-	NS
IBDU X Ih X NR	-	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[†]Number in brackets represents days after fertilizer application.
[‡]Rate not included in 1983.
[§]Nty = nitrapyrin.
[¶]These plots were not sampled.
[#]Ih = inhibitors.

Table 5-2. Interactions (DCD Q X NR L **) of DCD rate and N rate effects on soil inorganic N concentration 6 days after fertilizer application (Hastings, 1984).

	DCD Rate (kg/ha)		
N Rate	0	5.6	11.2
kg/ha	mg/kg N		
67	83.2	87.7	63.7 Lx
134	126.2	124.6	118.8 NS
202	202.0	147.6	214.5 Q*
	L***	L***	L***

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table 5-3. Interaction (Nty R X NR Q x) of nitrapyrin rate and N rate effects on soil inorganic N concentration 6 days after fertilizer application (Hastings, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	mg/kg N	
67	69.2	94.7 *
134	152.0	145.9 NS
202	191.5	241.6 x
	L***	L***

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1} resulted in an increase in SIN concentration from 69.2 to 94.7 mg kg^{-1}. With 202 kg ha^{-1} N, increased nitrapyrin rate resulted in an increase in SIN concentration from 191.5 to 241.6 mg kg^{-1}.

In 1984 on day 6 (Table 5-1), mean SIN concentration was higher with nitrapyrin (149.2 mg kg^{-1}) than with DCD (126.2 mg kg^{-1}). Mean soil inorganic N concentration was higher with the inhibitors (137.6 mg kg^{-1}) than with IBDU (114.0 mg kg^{-1}).

<u>Pre-emergence stage</u>. Soil was sampled at the pre-emergence stage at 16, 13, and 18 days after fertilizer application in 1983 at Gainesville and Hastings, and in 1984 at Hastings, respectively. At the pre-emergence stage, SIN concentration means increased with increases in N rate in all year-location combinations that were sampled (Table 5-4). In 1983 on day 16 at Gainesville, SIN concentration increased from 74.5 to 97.1 mg kg^{-1} with an increase in N rate from 134 to 202 kg ha^{-1}. In 1984 on day 13 at Gainesville, SIN concentration increased from 33.1 to 68.2 mg kg^{-1} with an increase in N rate from 67 to 202 kg ha^{-1}. In 1984 on day 18 at Hastings, SIN concentration increased from 85.0 to 211.1 mg kg^{-1} with an increase in N rate from 67 to 202 kg ha^{-1}.

In 1984 on day 13 at Gainesville, DCD rate interacted with N rate effects on SIN concentration (Table 5-5). With

Table 5-4. Effects of N rate and amendment on soil inorganic N at the pre-emergence stage of potato.

Independent Variable	Gainesville 1983[16][†]	Gainesville 1984[13]	Hastings 1984[18]
	mg/kg N		
N Rate			
67 kg/ha	-[‡]	33.1	85.0
134 kg/ha	74.5	48.1	157.7
202 kg/ha	97.1	68.2	211.1
	**	L***	L***Q*
DCD Rate			
0.0 kg/ha	85.8	51.5	165.5
5.6 kg/ha	96.2	40.2	147.2
11.2 kg/ha	71.8	50.2	151.6
	NS	Q***	L*Q*
Nty[§] Rate			
0.56 kg/ha	79.7	49.3	164.3
1.12 kg/ha	96.9	49.6	153.3
	NS	NS	NS
DCD v Nty	NS	x	x
IBDU as 1/3 of N	84.4	58.1	125.9
IBDU v Ih[¶]	NS	***	***
Interactions			
DCD L X NR	NS	NS	Qx
DCD Q X NR	NS	Q*	L*
Nty R X NR	*	NS	L**
DCD v Nty X NR	NS	Lx	NS
IBDU v Ih X NR	NS	L**	L**

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[†]Number in brackets represents days after fertilizer application.
[‡]Rate not included in 1983.
[§]Nty = nitrapyrin.
[¶]Ih = inhibitors.

Table 5-5. Interactions (DCD Q X NR Q *, DCD L X NR Q x, and DCD Q X NR L *) of DCD and N rate effects on soil inorganic N concentration at the pre-emergence stage of potato (1984).

	Gainesville [13]†			Hastings [18]		
	DCD Rate (kg/ha)			DCD Rate (kg/ha)		
N Rate	0.0	5.6	11.2	0.0	5.6	11.2
kg/ha	mg/kg N					
67	35.7	31.6	35.5 NS	87.5	88.3	72.5 x
134	54.8	33.4	50.5 Q***	159.9	146.3	164.6 NS
202	64.0	55.6	74.4 NS	249.0	207.0	217.8 L*Q*
	L*** Q**	L***	L***	L***	L***	L*** Q*

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

†Number in brackets represents days after fertilizer application.

Table 5-6. Interactions (Nty R X NR * and Nty R X NR L **) of nitrapyrin and N rate effects on soil inorganic N concentration at the pre-emergence stage of potato.

	Gainesville 1983 [16]†		Hastings 1984 [18]	
	Nitrapyrin Rate (kg/ha)		Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12	0.56	1.12
kg/ha	mg/kg N			
67	-‡	-	88.7	99.3 NS
134	73.92	63.2 NS	167.3	166.7 NS
202	85.5	130.6 *	236.8	193.8 **
	NS	NS	L***	L*** Qx

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

†Numbers in brackets represent days after fertilizer application.
‡Rate not included in 1983.

134 kg ha^{-1} N, SIN concentration decreased from 54.8 to 33.4 mg kg^{-1} with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. With a further increase in DCD to 11.2 kg ha^{-1}, SIN concentration increased to 50.5 mg kg^{-1}. With 67 and 202 kg ha^{-1} N on day 13, SIN concentration was not influenced by DCD rate.

In 1984 on day 18 at Hastings, DCD rate interacted with N rate (Table 5-5). With 67 kg ha^{-1} N, SIN concentration decreased from 87.5 to 72.5 mg kg^{-1} with an increase in DCD rate from 0 to 11.2 kg ha^{-1}. With 134 kg ha^{-1} N, DCD rate had no effect. With 202 kg ha^{-1} N, SIN concentration decreased from 249.0 to 207.0 mg kg^{-1} with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. A further increase in DCD to 11.2 kg ha^{-1} had no effect on SIN concentration. In 1983 on day 16 at Gainesville, nitrapyrin rate interacted with N rate (Table 5-6). With 202 kg ha^{-1} N, SIN concentration increased from 85.5 to 130.6 mg kg^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 134 kg ha^{-1} N, nitrapyrin rate had no effect.

In 1984 on day 18 at Hastings, nitrapyrin rate interacted with N rate (Table 5-6). With 202 kg ha^{-1} N, SIN concentration decreased from 236.8 to 193.8 mg kg^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 67 and 134 kg ha^{-1} N, nitrapyrin rate had no effect.

In 1984 on day 13 at Gainesville, the DCD v nitrapyrin contrast interacted with N rate (Table 5-7). With 134 kg ha^{-1} N, mean SIN concentration was higher with nitrapyrin

Table 5-7. Interaction (DCD v Nty X NR L x) of DCD v nitrapyrin and N rate effects on soil inorganic N concentration 13 days after fertilizer application (Gainesville, 1984).

N Rate	DCD	Nitrapyrin
kg/ha	mg/kg N	
67	33.6	30.5 NS
134	42.0	49.3 *
202	60.0	68.5 NS
	L***	L***
	Qx	

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

(49.3 mg kg^{-1}) than with DCD (41.0 mg kg^{-1}). With 67 and 202 kg ha^{-1} N, mean SIN concentration was similar with the two inhibitors. In 1984 on day 18 at Hastings, mean SIN concentration (Table 5-4) was higher with nitrapyrin (158.8 mg kg^{-1}) than with DCD (149.4 mg kg^{-1}).

In 1984 on day 13 at Gainesville, the IBDU v inhibitors contrast interacted with N rate (Table 5-8). With 202 kg ha^{-1} N, mean SIN concentration was higher with IBDU (88.2 mg kg^{-1}) than with inhibitors (64.3 mg kg^{-1}). With 67 and 134 kg ha^{-1} N, mean SIN concentration was similar with the two amendment types.

In 1984 on day 18 at Hastings, the IBDU v inhibitors contrast interacted with N rate (Table 5-8). With all N rates, SIN concentration means were higher with inhibitors than with IBDU, but the magnitude of the difference in mean SIN concentration between the two amendment types, increased with increasing N rate.

Vegetative stage. Soil was sampled at the vegetative stage of potato growth on 35, 31, 31, and 32 days after fertilizer application in 1983 and 1984 at Gainesville, and 1983 and 1984 at Hastings, respectively. At the vegetative stage, SIN concentration increased with increases in N rate in all year-location combinations (Table 5-9). In 1983 on day 35 at Gainesville, SIN concentration increased from 47.5 to 61.0 mg kg^{-1} with an increase in N rate from 134 to 202 kg ha^{-1}. In 1984 on day 31 at Gainesville, SIN

Table 5-8. Interaction (IBDU v Ih X NR L **) of IBDU v inhibitors, and N rate effects on soil inorganic N concentration at the pre-emergence stage of potato (1984).

	Gainesville [13]†		Hastings [18]	
N Rate	IBDU	Inhibitors	IBDU	Inhibitors
kg/ha	mg/kg N			
67	34.6	32.1 NS	74.0	87.2 x
134	51.4	45.6 NS	141.5	161.2 x
202	88.2	64.3 **	162.3	213.9 ***
	L***	L***	L***	L***
			Q**	Qx

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

†Numbers in brackets represent days after fertilizer application.

Table 5-9. Effects of N rate and amendment on soil inorganic N concentration at the vegetative stage of potato.

Independent Variable	Gainesville 1983[35][†]	Gainesville 1984[31]	Hastings 1983[31]	Hastings 1984[32]
	mg/kg N			
N Rate				
67 kg/ha	-[‡]	27.0	-	21.7
134 kg/ha	47.5	41.7	2.4	32.2
202 kg/ha	61.0	52.7	3.1	41.0
	**	L***	x	L***
DCD Rate				
0.0 kg/ha	46.9	41.3	2.4	26.1
5.6 kg/ha	57.2	34.6	3.1	29.4
11.2 kg/ha	47.2	43.2	2.4	28.8
	NS	Q**	NS	NS
Nty[§] Rate				
0.56 kg/ha	50.3	38.7	2.3	29.7
1.12 kg/ha	57.0	36.6	2.7	29.6
	NS	NS	NS	NS
DCD v Nty	NS	NS	NS	NS
IBDU as 1/3 of N	66.8	48.3	3.4	46.4
IBDU v Ih[¶]	*	***	NS	***
Interactions				
DCD L X NR	NS	Q*	NS	NS
DCD Q X NR	*	Q*	NS	NS
Nty R X NR	NS	L**	NS	NS
DCD v Nty X NR	NS	NS	NS	NS
IBDU v Ih X NR	NS	Q**	NS	L**

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[†]Numbers in brackets represent days after fertilizer application.
[‡]Rate not included in 1983.
[§]Nty = nitrapyrin.
[¶]Ih = inhibitors.

concentration increased from 27.0 to 52.7 mg kg^{-1} with an increase in N rate from 67 to 202 kg ha^{-1}. In 1983 on day 31 at Hastings, SIN concentration increased from 2.4 to 3.1 mg kg^{-1} with an increase in N rate from 134 to 202 kg ha^{-1}. In 1984 on day 32 at Hastings, SIN concentration increased from 21.7 to 41.0 mg kg^{-1} with an increase in N rate from 67 to 202 kg ha^{-1}.

In 1984 on day 31 at Gainesville, DCD rate interacted with N rate (Table 5-10). With 67 kg ha^{-1} N, DCD had no effect. With 134 kg ha^{-1} N, SIN concentration decreased from 45.7 to 31.6 mg kg^{-1} with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. With a further increase in DCD to 11.2 kg ha^{-1}, SIN concentration increased to 39.3 mg kg^{-1}, which was less than the concentration with 0 DCD. With 202 kg ha^{-1} N, a similar pattern of SIN concentration occurred, decreasing from 50.8 to 45.6 mg kg^{-1}, then increasing to 61.3 mg kg^{-1} with increases in DCD rate from 0, to 5.6, to 11.2 kg ha^{-1}, respectively. At this N rate, however, the SIN concentration with 11.2 kg ha^{-1} DCD was higher than that with 0 DCD on day 31 in 1984 at Hastings. At the vegetative stage, SIN concentration was not influenced by DCD rate in either year at Hastings.

In 1984 on day 31 at Gainesville, nitrapyrin rate interacted with N rate effects on SIN concentration (Table 5-11). With 67 kg ha^{-1} N, an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1} resulted in an increase in SIN

Table 5-10. Interactions (DCD L X NR Q * and DCD Q X NR Q *) of DCD and N rate effects on soil inorganic N concentration 31 days after fertilizer application (Gainesville, 1984).

	DCD Rate (kg/ha)		
N Rate	0	5.6	11.2
kg/ha	mg/kg N		
67	27.3	26.5	29.0 NS
134	45.7	31.6	39.3 LxQ***
202	50.8	45.6	61.3 LxQx
	L***	L***	L***
	Q*		

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

Table 5-11. Interaction (Nty R X NR Q ***) of nitrapyrin and N rate effects on soil inorganic N concentration 31 days after fertilizer application (Gainesville, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	mg/kg N	
67	18.2	27.6 ***
134	41.4	35.6 x
202	56.6	46.6 NS
	L ***	L ***

Nonsignificant (NS) or significant at the 0.1 (x), or 0.001 (***) probability levels, respectively.

concentration from 18.2 to 27.6 mg kg^{-1}. With 134 kg ha^{-1} N, an increase in nitrapyrin rate resulted a decrease in SIN concentration from 41.4 to 35.6 mg kg^{-1}. With 202 kg ha^{-1} N, nitrapyrin rate had no effect on SIN concentration on day 31 in 1984 at Gainesville.

At the vegetative stage, SIN concentration means were higher with IBDU than with inhibitors in 1984 at both locations, and in 1983 at Gainesville (Table 5-9). In 1983 on day 35 at Gainesville, mean SIN concentration was 66.8 mg kg^{-1} with IBDU and 52.9 mg kg^{-1} with inhibitors. In 1984 on day 31 at Gainesville, the IBDU v inhibitors contrast interacted with N rate (Table 5-12). With 67 kg ha^{-1} N, mean SIN concentration was 33.0 mg kg^{-1} with IBDU and 25.3 mg kg^{-1} with inhibitors. With 134 kg ha^{-1} N, mean SIN concentration was 56.6 mg kg^{-1} with IBDU and 37.0 mg kg^{-1} with inhibitors. With 202 kg ha^{-1} N, mean SIN concentration was similar with the two types of amendments. In 1984 on day 32 at Hastings (Table 5-9), mean SIN concentration was 46.4 mg kg^{-1} with IBDU and 29.4 mg kg^{-1} with inhibitors. The interaction between N rate and IBDU v inhibitors (data not shown) indicated a greater N rate effect with IBDU than with inhibitors.

Tuber initiation stage. The soil was sampled at the tuber initiation stage of potato growth only in 1984, 45 and 46 days after fertilizer application at Gainesville, and Hastings, respectively. At tuber initiation, SIN

Table 5-12. Interaction (IBDU v Ih X NR L *) of IBDU v inhibitors, and N rate effects on soil inorganic N concentration 31 days after fertilizer application (Gainesville, 1984).

N Rate	IBDU	Inhibitors
kg/ha	——mg/kg N——	
67	33.0	25.3 ***
134	56.6	37.0 ***
202	55.3	52.5 NS
	L***	L***

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

concentration increased with increases in N rate at both locations (Table 5-13). On day 45 at Gainesville, SIN concentration increased from 14.7 to 39.3 mg kg^{-1} with an increase in N rate from 67 to 202 kg ha^{-1}. On day 46 at Hastings, SIN concentration increased from 12.3 to 40.1 mg kg^{-1} with an increase in N rate from 67 to 202 kg ha^{-1}.

On day 45 at Gainesville, SIN concentration decreased from 25.4 to 21.1 mg kg^{-1} with an increase in DCD rate from 0 to 5.6 kg ha^{-1} (Table 5-13). With a further increase in DCD to 11.2 kg ha^{-1}, SIN concentration increased to 26.5 mg kg^{-1} which was not different that with 0 DCD.

On day 45 at Gainesville, nitrapyrin rate interacted with N rate (Table 5-14). With 67 kg ha^{-1} N, SIN concentration increased from 9.4 to 14.4 mg kg^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 202 kg ha^{-1} N, SIN concentration decreased from 39.9 to 20.8 mg kg^{-1} with an increase in nitrapyrin rate. With 134 kg ha^{-1} N, nitrapyrin rate had no effect.

At both locations, SIN concentration at tuber initiation was influenced by an interaction between DCD v nitrapyrin and N rate. On day 45 at Gainesville (Table 5-15), mean SIN concentration was higher with DCD than with nitrapyrin with 67 (14.5 v 11.9 mg kg^{-1} and 202 kg ha^{-1} N (39.2 30.3 mg kg^{-1}), but was lower with 134 kg ha^{-1} N (17.6 v 24.8 mg kg^{-1}). On day 46 at Hastings (Table 5-16), mean SIN concentration was higher with nitrapyrin than with DCD, with

Table 5-13. Effects of nitrogen rate and amendment on soil inorganic N concentration at the tuber initiation stage.

Independent Variable	Gainesville 1984[45][†]	Hastings 1984[46]
	mg/kg N	
N Rate		
67 kg/ha	14.7	12.3
134 kg/ha	25.9	24.4
202 kg/ha	39.3	40.1
	L***	L***
DCD Rate		
0.0 kg/ha	25.4	26.6
5.6 kg/ha	21.1	23.6
11.22 kg/ha	26.5	24.8
	Qx	NS
Nty[‡] Rate		
0.56 kg/ha	24.2	23.2
1.12 kg/ha	20.5	26.1
	NS	NS
DCD v Nty	NS	NS
IBDU as 1/3 of N	42.1	29.7
IBDU v Ih[§]	***	***
Interactions		
DCD L X NR	NS	NS
DCD Q X NR	NS	NS
Nty R X NR	L**	NS
DCD v Nty X NR	Q**	L*Q*
IBDU v Ih X NR	Q*	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[†]Numbers in brackets represent days after fertilizer application.
[‡]Nty = nitrapyrin.
[§]Ih = inhibitors.

Table 5-14. Interactions (Nty R X NR L **) of nytrapyrin and N rate effects on soil inorganic N concentration 45 days after fertilizer application (Gainesville, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	mg/kg N	
67	9.4	14.4 *
134	23.5	26.2 NS
202	39.9	20.8 **
	L***	Qx

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table 5-15. Interaction (DCD v nitrapyrin X NR Q **) of DCD v nitrapyrin, and N rate effects on soil inorganic N concentration 45 days after fertilizer application (Gainesville, 1984).

N Rate	DCD	Nitrapyrin
kg/ha	mg/kg N	
67	14.5	11.9 x
134	17.6	24.8 *
202	39.2	30.3 x
	L***	L***
	Q**	

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table 5-16. Interaction (DCD v nitrapyrin X NR L * and X NR Q *) of DCD v nitrapyrin, and N rate effects on soil inorganic N concentration 46 days after fertilizer application (Hastings, 1984).

N Rate	DCD	Nitrapyrin
kg/ha	mg/kg N	
67	10.5	12.4 *
134	21.8	26.2 x
202	40.4	35.3 *
	L***	L***
	Qx	

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

67 (12.4 v 10.5 mg kg^{-1}) and 134 kg ha^{-1} N (26.2 v 21.8 mg kg^{-1}), but was lower with 202 kg ha^{-1} N (35.3 v 40.4 mg kg^{-1}).

At the tuber initiation stage, mean SIN concentration was higher with IBDU than with inhibitors at both locations (Table 5-13). On day 45 at Gainesville, mean SIN concentration was 42.1 mg kg^{-1} with IBDU and 23.1 mg kg^{-1} with inhibitors. On day 46 at Hastings, mean SIN concentration was 29.7 mg kg^{-1} with IBDU and 24.4 mg kg^{-1} with inhibitors.

Tuber bulking stage. Soil was sampled at the tuber bulking (enlargement) stage of potato growth on 59, 69, 61, and 74 days after fertilizer application in 1983 and 1984 at Gainesville, and in 1983 and 1984 at Hastings, respectively. Increases in N rate increased SIN concentration at tuber bulking in 1983 at Gainesville, and in 1984 in both locations (Table 5-17). In 1983 on day 59 at Gainesville, SIN concentration increased from 18.5 to 27.2 mg kg^{-1} with an increase in N rate from 134 to 202 kg ha^{-1}. In 1984 on day 69 at Gainesville, SIN concentration was not influenced by an increase in N rate from 67 to 134 kg ha^{-1}. With a further increase in N rate to 202 kg ha^{-1}, however, SIN concentration increased from 10.1 to 23.2 mg kg^{-1}.

In 1983 on day 59 at Gainesville, SIN concentration at tuber bulking increased from 18.9 to 24.6 mg kg^{-1} with an increase in DCD rate from 0 to 5.6 kg ha^{-1}. With a further increase in DCD rate to 11.2 kg ha^{-1}, SIN concentration

Table 5-17. Effects of nitrogen rate and amendment on soil inorganic N concentration at the tuber bulking stage.

Independent Variable	Gainesville 1983[59]†	Gainesville 1984[69]	Hastings 1983[61]	Hastings 1984[74]
	mg/kg N			
N Rate				
67 kg/ha	-‡	7.8	-	6.9
134 kg/ha	18.5	10.1	11.2	8.6
202 kg/ha	27.2	23.2	13.2	15.5
	***	L*** Q***	NS	L*** Q***
DCD Rate				
0.0 kg/ha	18.9	11.2	10.1	9.5
5.6 kg/ha	24.6	12.8	12.5	9.8
11.2 kg/ha	17.0	14.6	14.4	9.5
	Q*	L*	NS	NS
Nty§ Rate				
0.56 kg/ha	22.4	13.9	14.5	9.9
1.12 kg/ha	22.9	12.2	10.9	10.0
	NS	NS	NS	NS
DCD v Nty	NS	NS	NS	NS
IBDU as 1/3 of N	30.6	17.5	10.8	13.3
IBDU v Ih¶	***	***	NS	***
Interactions				
DCD L X NR	NS	Lx	NS	NS
DCD Q X NR	NS	NS	NS	NS
Nty R X NR	NS	Lx	NS	NS
DCD v Nty X NR	NS	NS	NS	NS
IBDU v Ih X NR	**	L** Q**	NS	L**

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

†Numbers in brackets represent days after fertilizer application.
‡Rate not included in 1983.
§Nty = nitrapyrin.
¶Ih = inhibitors.

decreased to 17.0 mg kg^{-1}, which was not different from that with 0 DCD.

In 1984 on day 69 at Gainesville, DCD rate interacted with N rate (Table 5-18). With 67 kg ha^{-1} N, an increase in DCD rate from 0 to 5.6 kg ha^{-1} had no effect on SIN concentration. A further increase in DCD to 11.2 kg ha^{-1} resulted in an increase in SIN concentration from 6.8 to 8.4 mg kg^{-1}. With 134 kg ha^{-1} N, DCD rate had no effect on SIN concentration. With 202 kg ha^{-1} N, SIN concentration increased from 16.9 to 24.6 mg kg^{-1} with an increase in DCD rate from 0 to 11.2 kg ha^{-1}.

In 1984 on day 69 at Gainesville, nitrapyrin rate interacted with N rate (Table 5-19). With 202 kg ha^{-1} N, SIN concentration decreased from 23.7 to 17.4 mg kg^{-1} with an increase in nitrapyrin rate from 5.6 to 1.12 kg ha^{-1}. With 67 and 134 kg ha^{-1} N, nitrapyrin rate had no effect on SIN concentration.

In 1983 at both locations and in 1984 at Hastings (Table 5-17), the IBDU v inhibitors contrast interacted with N rate effects on SIN concentration at tuber bulking. In 1983 on day 59 at Gainesville (Table 5-20), with 202 kg ha^{-1} N, mean SIN concentration was higher with IBDU (40.5 mg kg^{-1}) than with inhibitors (25.8 mg kg^{-1}). With 134 kg ha^{-1} N, SIN concentration means were similar with the two amendments types. In 1984 on day 69 at Gainesville (Table 5-20), with 67 kg ha^{-1} N, mean SIN concentration with IBDU was

Table 5-18. Interaction (DCD L X NR L *) of DCD and N rate effects on soil inorganic N concentration 69 days after fertilizer application (Gainesville, 1984).

	DCD Rate (kg/ha)		
N Rate	0	5.6	11.2
kg/ha	mg/kg N		
67	7.1	6.8	8.4 L*Q*
134	9.8	8.8	10.6 NS
202	16.9	22.7	24.6 L*
	L***	L***	L***
	Q*	Qx	

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

Table 5-19. Interaction (Nty R X NR L x) of nitrapyrin and N rate effects on soil inorganic N concentration 69 days after fertilizer application (Gainesville, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	mg/kg N	
67	7.3	7.3 NS
134	10.8	11.8 NS
202	23.7	17.4 x
	L***	L***
	Qx	

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

Table 5-20. Interactions (IBDU v Ih X NR **, IBDU v Ih X NR L **, and X NR Q **) of IBDU v inhibitors, and N rate effects on soil inorganic N concentration at the tuber bulking stage.

	Gainesville 1983 [59][†]		Gainesville 1984 [69]	
N Rate	IBDU	Inhibitors	IBDU	Inhibitors
kg/ha	mg/kg N			
67	-[‡]	-	9.8	7.5 ***
134	20.6	18.0 NS	8.9	10.5 *
202	40.5	25.8 **	33.9	22.1 ***
	L*	L***	L***	L***
			Q***	Q***

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[†]Numbers in brackets represent days after fertilizer application.
[‡]Rate not included in 1983.

Table 5-21. Interaction (IBDU v Ih X NR L *) of IBDU v inhibitors, and N rate effects on soil inorganic N concentration 74 days after fertilizer application (Hastings, 1984).

N Rate	IBDU	Inhibitors
kg/ha	mg/kg N	
67	7.9	6.9 *
134	10.5	8.2 **
202	21.5	14.3 ***
	L***	L***
	Q***	Q*

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

higher (9.8 mg kg^{-1}) than with inhibitors (7.5 mg kg^{-1}). With 134 kg ha^{-1} N, mean SIN concentration was higher with inhibitors (10.5 mg kg^{-1}) than with IBDU (8.9 kg ha^{-1}). With 202 kg ha^{-1} N, mean SIN concentration was higher with IBDU (33.9 mg kg^{-1}) than with inhibitors (22.1 mg kg^{-1}). In 1984 on day 74 at Hastings (Table 5-21), at all N rates SIN concentration means were higher with IBDU than with inhibitors but the magnitude and significance of this difference increased with increasing N rate.

At tuber harvest. Soil was sampled at tuber harvest on 98, 108, and 103 days after fertilizer application in 1983 and 1984 at Gainesville, and 1984 at Hastings, respectively. In 1983 on day 98 at Gainesville (Table 5-22), SIN concentration was not influenced by N rate. In 1984 on day 108 at Gainesville (Table 5-22), SIN concentration increased from 7.8 to 10.3 mg kg^{-1} with an increase in N rate from 67 to 202 kg ha^{-1}. In 1984 on day 103 at Hastings, SIN concentration was not influenced by an increase in N rate from 67 to 134 kg ha^{-1}, but with a further increase in N to 202 kg ha^{-1}, SIN concentration increased from 10.1 to 20.9 mg kg^{-1}.

In 1984 on day 103 at Hastings, DCD rate interacted with N rate (Table 5-23). With 202 kg ha^{-1} N, SIN concentration decreased from 24.8 to 16.7 mg kg^{-1} with an increase in DCD rate from 0 to 11.2 kg ha^{-1}. With 67 and 134 kg ha^{-1} N, DCD rate did not influence SIN concentration.

Table 5-22. Effects of N rate and amendment on soil inorganic N concentration at potato harvest.

Independent Variable	Gainesville 1983[98][†]	Gainesville 1984[108]	Hastings 1984[103]
	mg/kg N		
N Rate			
67 kg/ha	-[‡]	7.8	8.7
134 kg/ha	5.3	9.4	10.1
202 kg/ha	5.6	10.3	20.9
	NS	L***	L*** Q***
DCD Rate			
0.0 kg/ha	5.7	8.2	14.7
5.6 kg/ha	4.8	8.8	13.7
11.2 kg/ha	5.4	8.4	11.8
	NS	NS	L*
Nty[§] Rate			
0.56 kg/ha	4.9	9.2	13.0
1.12 kg/ha	5.2	10.3	13.9
	NS	NS	NS
DCD v Nty	NS	*	NS
IBDU as 1/3 of N	6.8	10.1	12.1
IBDU v Ih[¶]	*	NS	NS
Interactions			
DCD L X NR	NS	NS	L*
DCD Q X NR	NS	NS	NS
Nty R X NR	NS	L**	NS
DCD v Nty X NR	NS	NS	NS
IBDU v Ih X NR	x	NS	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

[†]Numbers in brackets represent days after fertilizer application.
[‡]Rate not included in 1983.
[§]Nty = nitrapyrin.
[¶]Ih = inhibitors.

Table 5-23. Interaction (DCD L X NR L *) of DCD and N rate effects on soil inorganic N concentration 103 days after fertilizer application (Hastings, 1984).

	DCD Rate (kg/ha)		
N Rate	0	5.6	11.2
kg/ha	mg/kg N		
67	9.2	9.5	8.6 NS
134	10.3	9.1	10.1 NS
202	24.8	22.5	16.7 L*
	L***	L***	L***
	Q**	Q*	

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table 5-24. Interaction (Nty R X NR L **) of nitrapyrin and N rate effects on soil inorganic N concentration 108 days after fertilizer application (Gainesville, 1984).

	Nitrapyrin Rate (kg/ha)	
N Rate	0.56	1.12
kg/ha	mg/kg N	
67	8.6	7.2 *
134	9.7	10.5 **
202	9.2	13.2 *
	NS	L**

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

In 1984 on day 108 at Gainesville, nitrapyrin rate interacted with N rate effects on SIN concentration (Table 5-24). With 67 kg ha^{-1} N, SIN concentration decreased from 8.6 to 7.2 mg kg^{-1} with an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1}. With 134 kg ha^{-1} N, SIN concentration increased from 9.7 to 10.5 mg kg^{-1} with an increase in nitrapyrin rate. With 202 kg ha^{-1} N, SIN concentration increased from 9.2 to 13.2 mg kg^{-1} with an increase in nitrapyrin rate.

In 1984 on day 108 at Gainesville, mean SIN concentration was higher with nitrapyrin (9.8 mg kg^{-1}) than with DCD (8.6 mg kg^{-1}) (Table 5-22). In 1983 on day 98 at Gainesville, the IBDU v inhibitors contrast interacted with N rate (Table 5-25). With 134 kg ha^{-1} N, mean SIN concentration was higher with IBDU (7.7 mg kg^{-1}) than with inhibitors (4.6 mg kg^{-1}). With 202 kg ha^{-1} N, SIN concentration means were similar with the two amendment types.

Extractable Soil DCD

Extractable Soil DCD Over Time

Extractable soil DCD concentration was quite variable from one year-location combination to another. The highest soil DCD concentration means observed in 1983 and 1984 at Gainesville, were in the 0.6 to 1.2 and 1.4 to 1.6 mg kg^{-1} ranges for the 5.6 and 11.2 kg ha^{-1} DCD rates, respectively (Figures 5-1 and 5-2). Measured soil DCD concentrations

Table 5-25. Interaction (IBDU v Ih X NR x) of IBDU v inhibitors, and N rate effects on soil inorganic N concentration 98 days after fertilizer application (Gainesville, 1983).

N Rate	IBDU	Inhibitors
kg/ha	mg/kg N	
134	7.7	4.6 **
202	5.8	5.6 NS
	x	*

Nonsignificant (NS) or significant at the 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

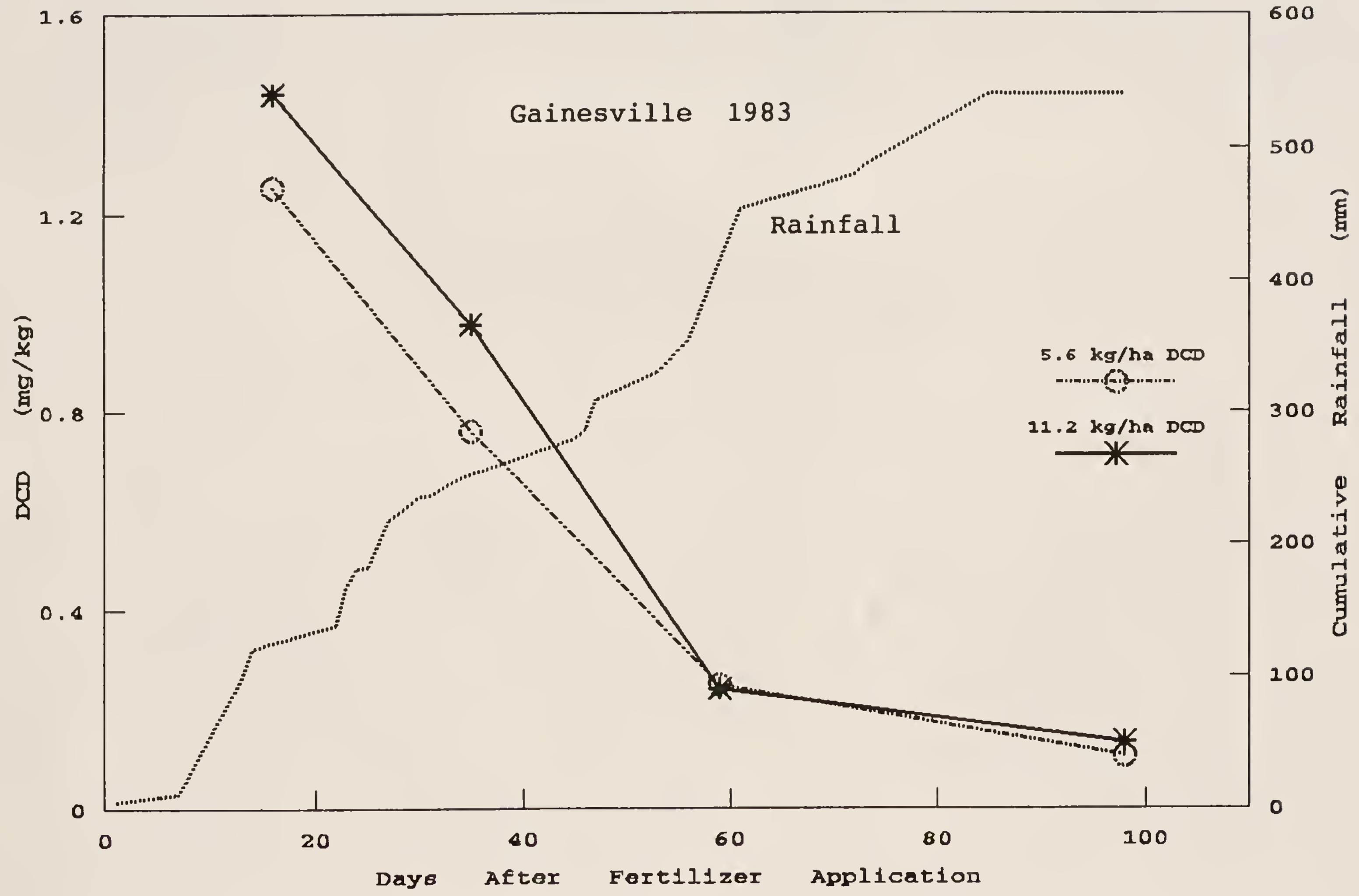

Figure 5-1. Effects of DCD rate on soil DCD concentration (Gainesville, 1983).

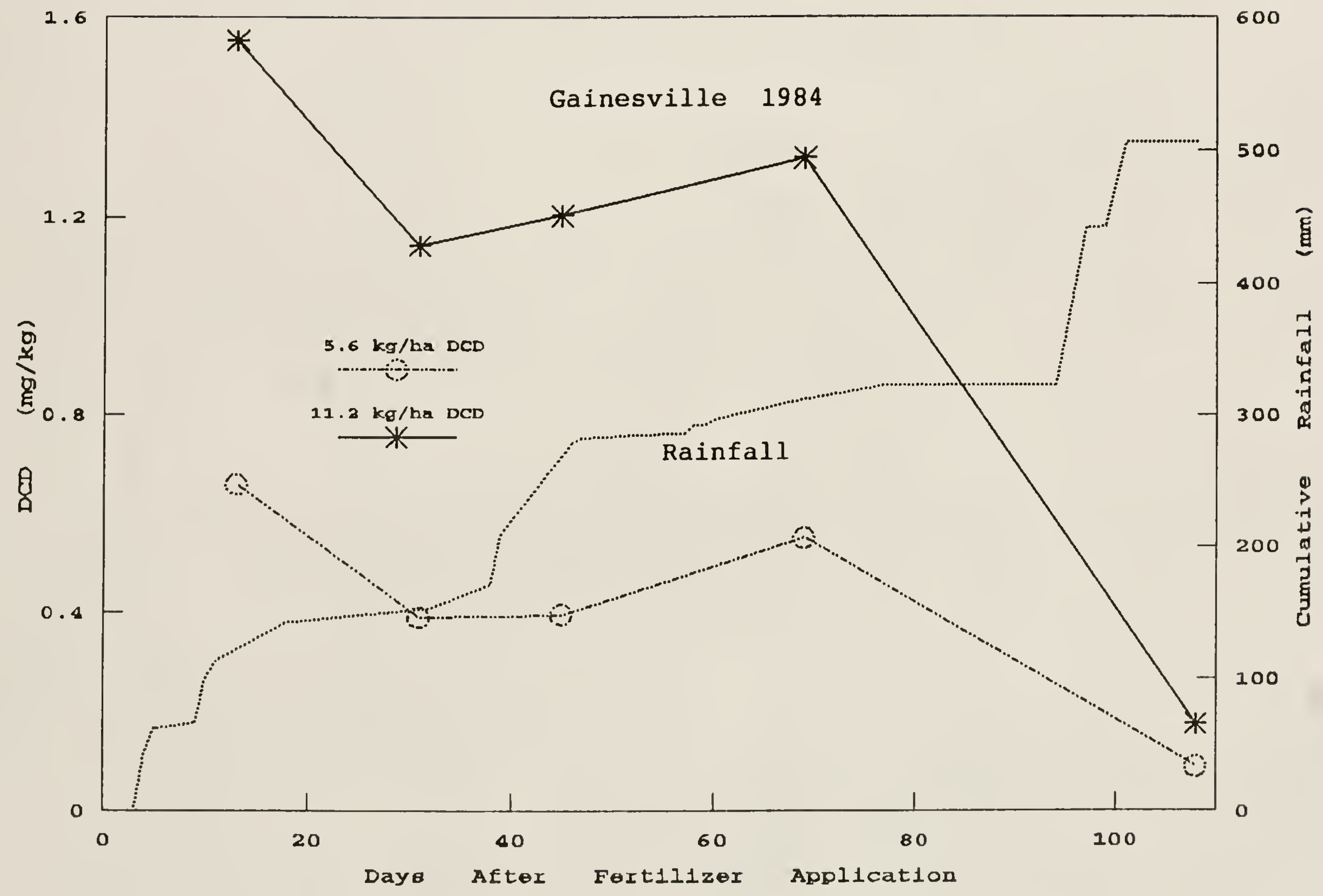

Figure 5-2. Effects of DCD rate on soil DCD concentration (Gainesville, 1984).

were not more than 0.8 mg kg^{-1} in 1983 at Hastings, and increased with time with the 11.2 kg ha^{-1} DCD rate (Figure 5-3). The highest concentrations of soil DCD occurred in 1984 at Hastings (Figure 5-4), with as much as 5 and 11 mg kg^{-1} with the 5.6 and 11.2 kg ha^{-1} DCD rates, respectively.

To estimate the time required for half of the applied DCD to disappear from a 30 cm deep rooting zone, a 1.35 g cm^{-3} soil bulk density was assumed (USDA, 1983) in converting observed soil DCD concentration means to a kg ha^{-1} basis. An extrapolated line was then assumed between the amount of DCD applied and the amount observed with the first sampling. The time required for half of the applied DCD to disappear from the rooting zone will be referred to as residence half time. This parameter is not a half life as not all DCD loss from the soil is due to decomposition. It was approximated that in 1983 at Gainesville, the DCD residence half time values were 50 and 30 days for the 5.6 and 11.2 kg ha^{-1} DCD rates, respectively. In 1984 at Gainesville, the estimated residence half time was 70 days with both DCD rates. In 1983 at Hastings, it was not possible to estimate the DCD residence half time because soil DCD concentration values did not decrease with time. In 1984 at Hastings, the estimated residence half time was 30 days with both DCD rates.

At Gainesville, where overhead irrigation was used, less than 0.2 mg kg^{-1} DCD remained in the soil at the end of

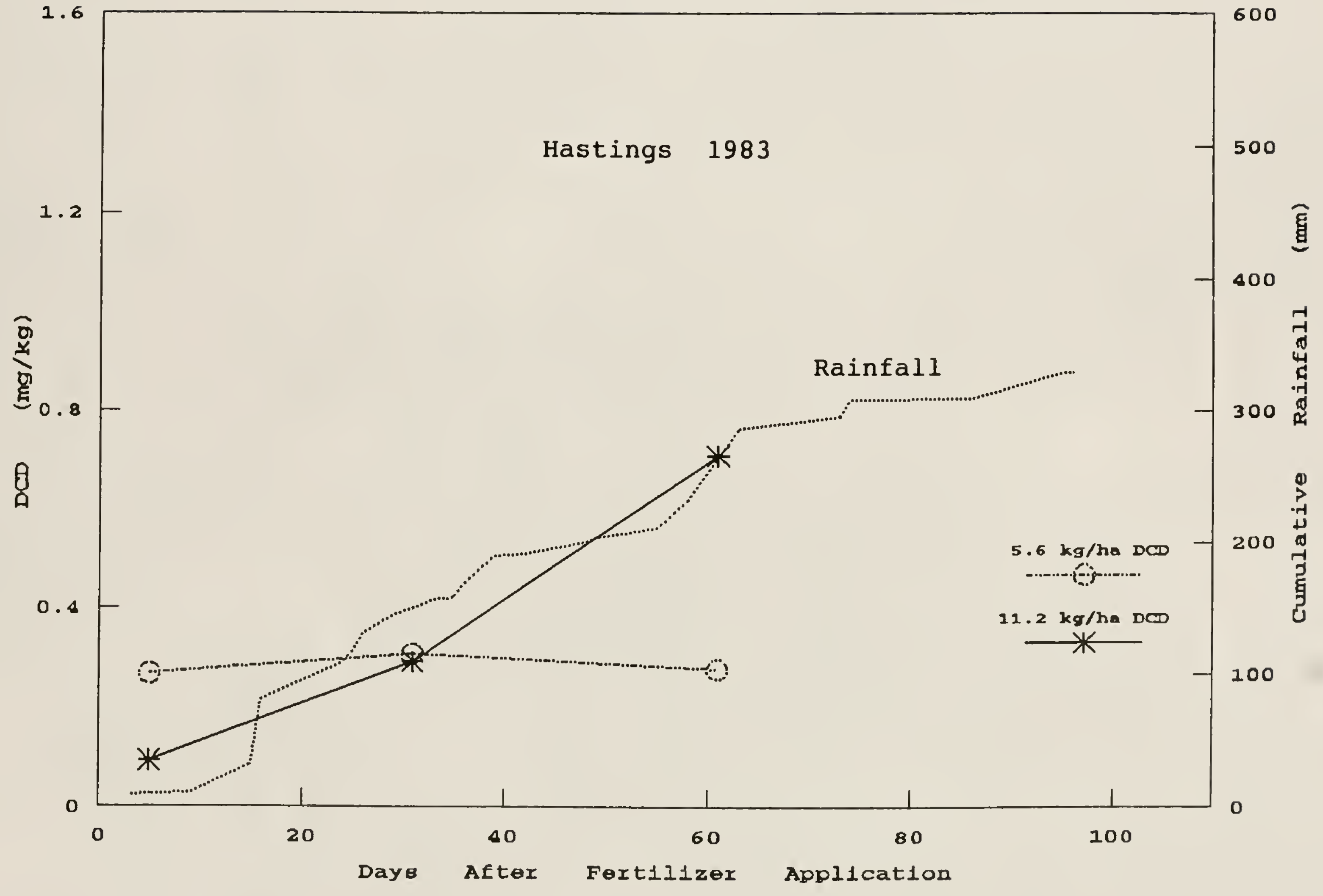

Figure 5-3. Effects of DCD rate on soil DCD concentration (Hastings, 1983).

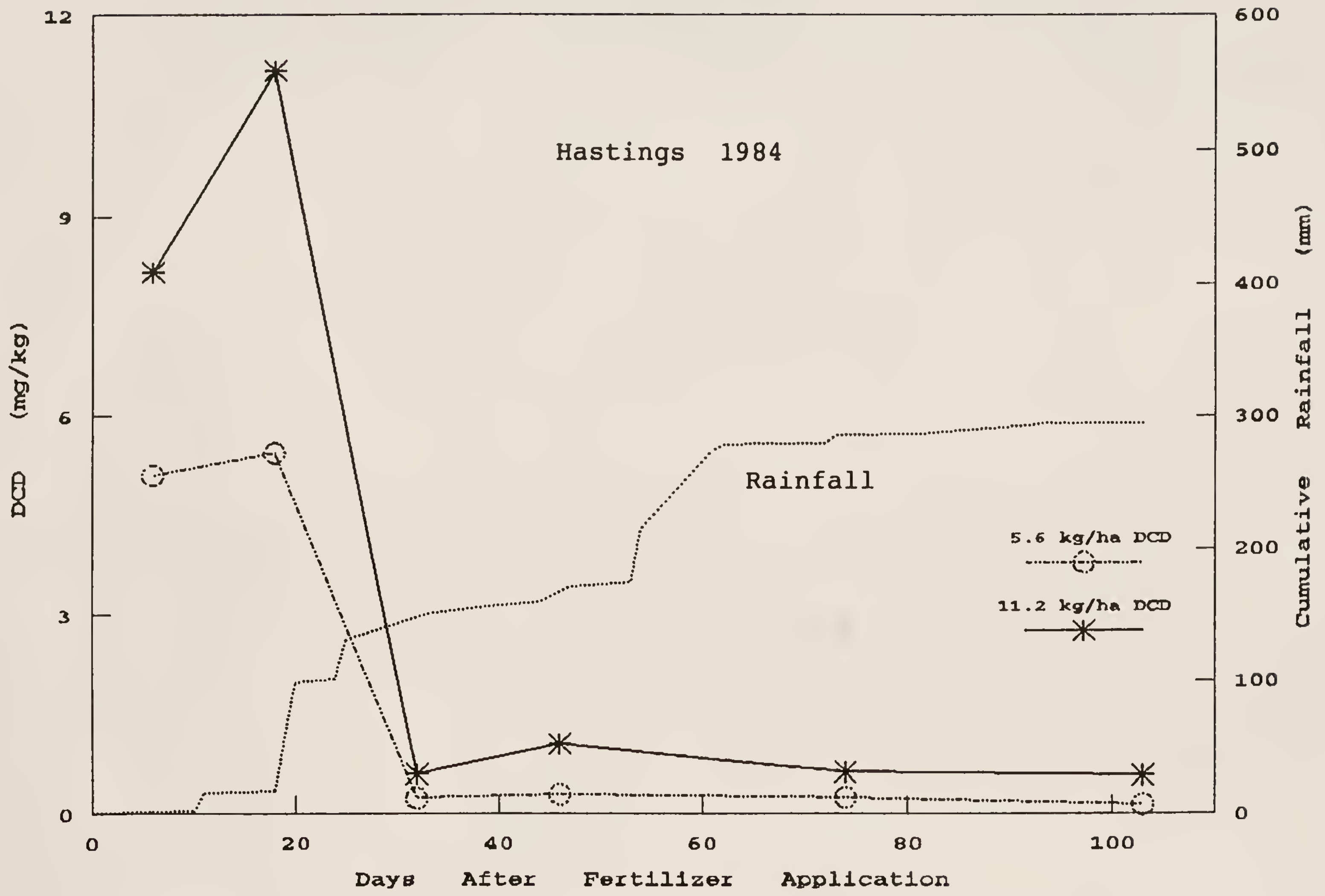

Figure 5-4. Effects of DCD rate on soil DCD concentration (Hastings, 1984).

the potato growing season in both years. At Hastings, where subsurface irrigation was used, as much as 0.6 mg kg^{-1} DCD remained in the soil at the end of the potato growing season.

DCD Rate Effects

In 1983 at Gainesville, DCD rate had no effect on soil DCD concentration (Figure 5-1, and Table 5-26). In 1984 at Gainesville, soil DCD concentration (Figure 5-2) was increased with an increase in DCD rate from 5.6 to 11.2 kg ha^{-1} on all but day 45.

In 1983 at Hastings, soil DCD concentration was not influenced by DCD rate (Table 5-27). In 1984 at Hastings, on days 6 and 18, DCD rate had no effect on soil DCD concentration. On days 32, 46, 74, and 103, and with the mean of all sampling dates, soil DCD concentration means were increased with an increase in DCD rate from 5.6 to 11.2 kg ha^{-1} (Table 5-27).

Rainfall

Recorded cumulative rainfall amounts at Gainesville and Hastings, in 1983 and 1984, are shown in Figures 5-1 to 5-4. In 1983 at Gainesville (Figure 5-1), rainfall amounts were high and evenly spaced throughout the growing season. In 1984 at Gainesville (Figure 5-2), total rainfall was adequate but droughts occurred from day 18 to day 38 and from day 46 to day 95. During these droughts water was

Table 5-26. Effects of N and DCD rates on soil DCD concentration (Gainesville).

Independent Variable	1983					1984					
	Days After Fertilizer Application					Days After Fertilizer Application					
	16	35	59	98	Mean	13	31	45	69	108	Mean
N Rate	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
DCD Rate	NS	NS	NS	NS	NS	*	x	NS	x	x	***
DCD R X NR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

Table 5-27. Effects of N and DCD rates on soil DCD concentration (Hastings).

Independent Variable	1983 Days After Fertilizer Application				1984 Days After Fertilizer Application						
	5	31	61	Mean	6	18	32	46	74	103	Mean
N Rate	*	NS	NS	x	NS	NS	NS	NS	NS	NS	NS
DCD Rate	NS	NS	NS	NS	NS	NS	***	***	**	***	***
DCD R X NR	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

supplied by overhead irrigation, sufficient to provide for crop requirements without promoting leaching of soil inorganic N. In 1983 at Hastings (Figure 5-3), total rainfall was low but evenly distributed except at the end of the growing season. In 1984 at Hastings (Figure 5-4), rainfall was low and poorly distributed, with relative droughts occurring from days 0 to 19, 34 to 53, and 62 to harvest. In both years at Hastings, supplemental water was provided from a subsurface irrigation system.

CHAPTER 6
UREA AND DCD APPLIED TO A FALLOW QUARTZIPSAMMENT

Soil NH_4^+-N

Analysis of variance of DCD effects on soil NH_4^+-N concentrations for all sampling dates and depths are shown in Table 6-1. Soil NH_4^+-N concentrations at five depths in the typic Quartzipsamment 14 days after urea and DCD application are shown in Figure 6-1. Soil NH_4^+-N concentration was not influenced by DCD rate at any of the sampled depths on day 14 (Table 6-1). On day 31 at the 15 to 30 cm depth, soil NH_4^+-N concentrations (Figure 6-2 and Table 6-1) were 21.8, 27.2, 14.0, and 22.0 mg kg^{-1}, with DCD rates of 0, 20, 40, and 60 kg ha^{-1}, respectively (a cubic effect). At the 91 to 122 cm depth, NH_4^+-N concentration decreased from 2.1 to 1.7 mg kg^{-1} with an increase in DCD rate from 0 to 60 kg ha^{-1}. At other depths, DCD rate did not influence soil NH_4^+-N concentration on day 31.

On day 46, NH4+-N concentration (Figure 6-3) was not influenced by DCD rate at any soil depth (Table 6-1). On day 60 (Figure 6-4), soil NH_4^+-N concentration at the 15 to 30 cm depth was increased from 7.7 to 21.1 mg kg^{-1} with an increase in DCD rate from 0 to 60 kg ha^{-1}.

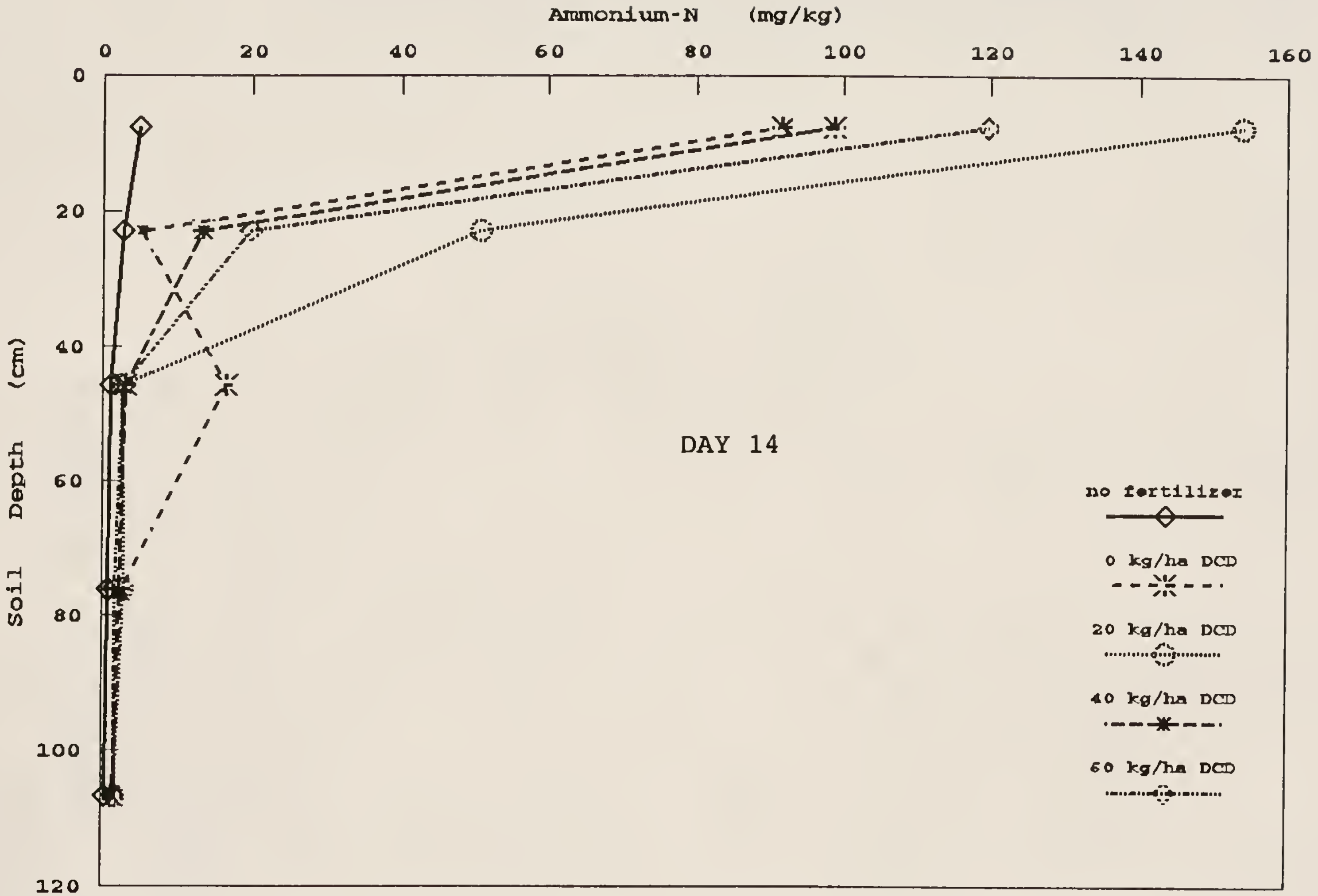

Figure 6-1. Effects of DCD rate on soil NH_4^+-N concentration with depth 14 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

Table 6-1. Effects of DCD rate on soil NH_4^+-N concentration at five depths over six sampling dates in a Quartzipsamment at Live Oak.

	Days Fertilizer After Application					
Depth (cm)	14	31	46	60	81	116
0-15	NS	NS	NS	NS	NS	NS
15-30	NS	C*	NS	Lx	NS	NS
30-61	NS	NS	NS	NS	NS	NS
61-91	NS	NS	NS	NS	Lx Q*Cx	NS
91-122	NS	Lx	NS	NS	Lx	NS
Profile	Cx	Cx	NS	NS	L*	NS

Nonsignificant (NS) or significant at the 0.1 (x), or 0.05 (*) probability levels, respectively.

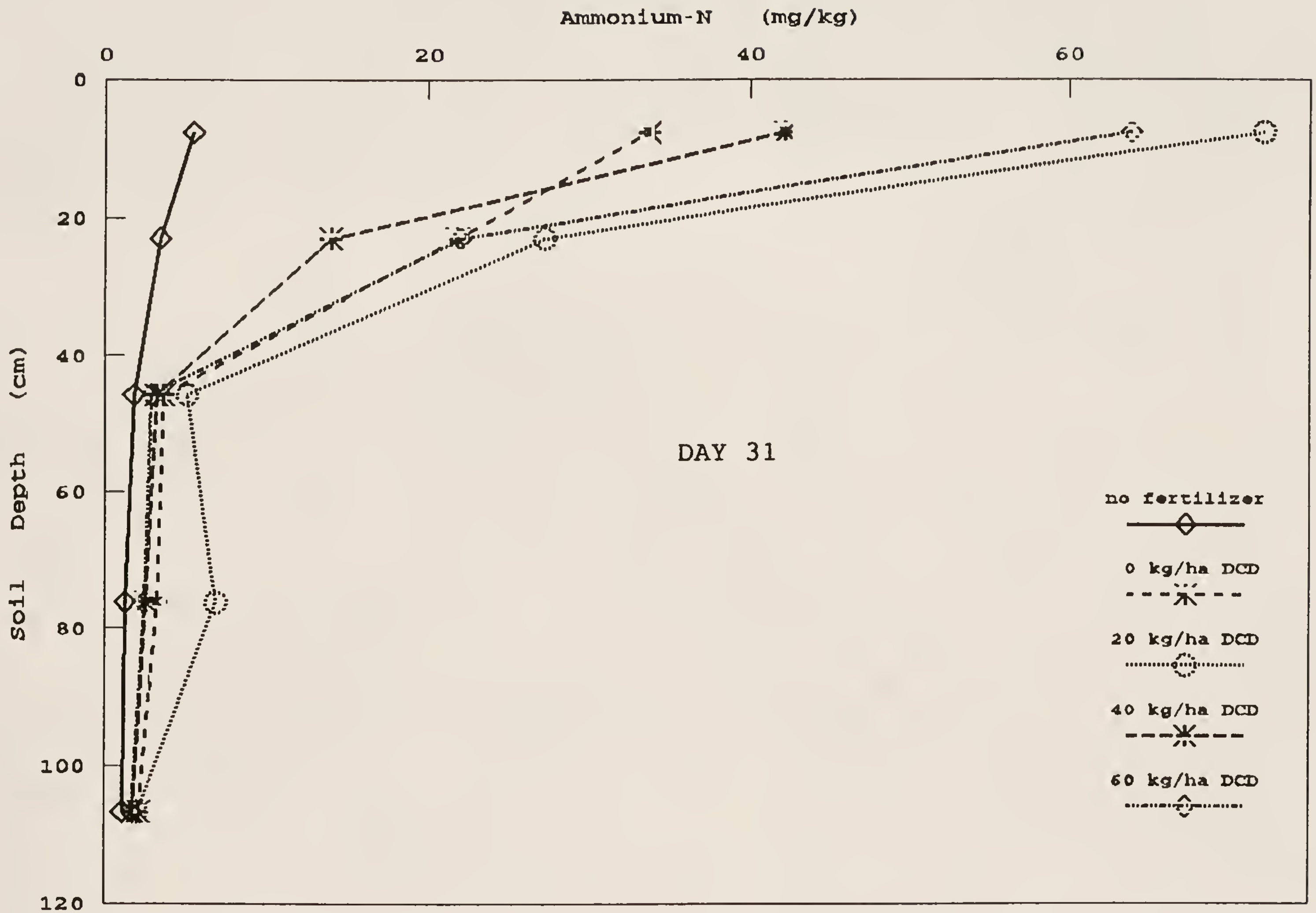

Figure 6-2. Effects of DCD rate on soil NH_4^+-N concentration with depth 31 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

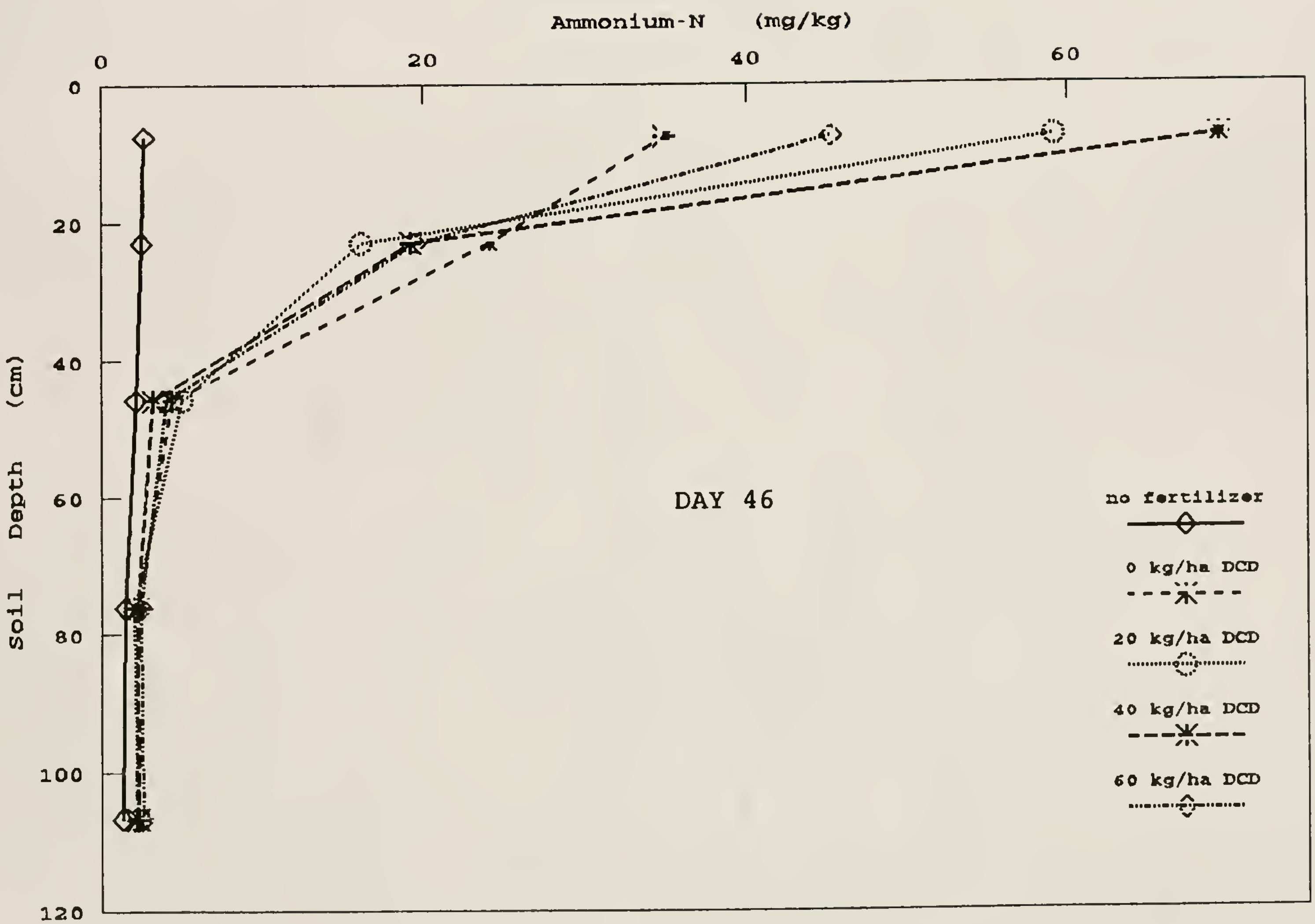

Figure 6-3. Effects of DCD rate on soil NH_4^+-N concentration with depth 46 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

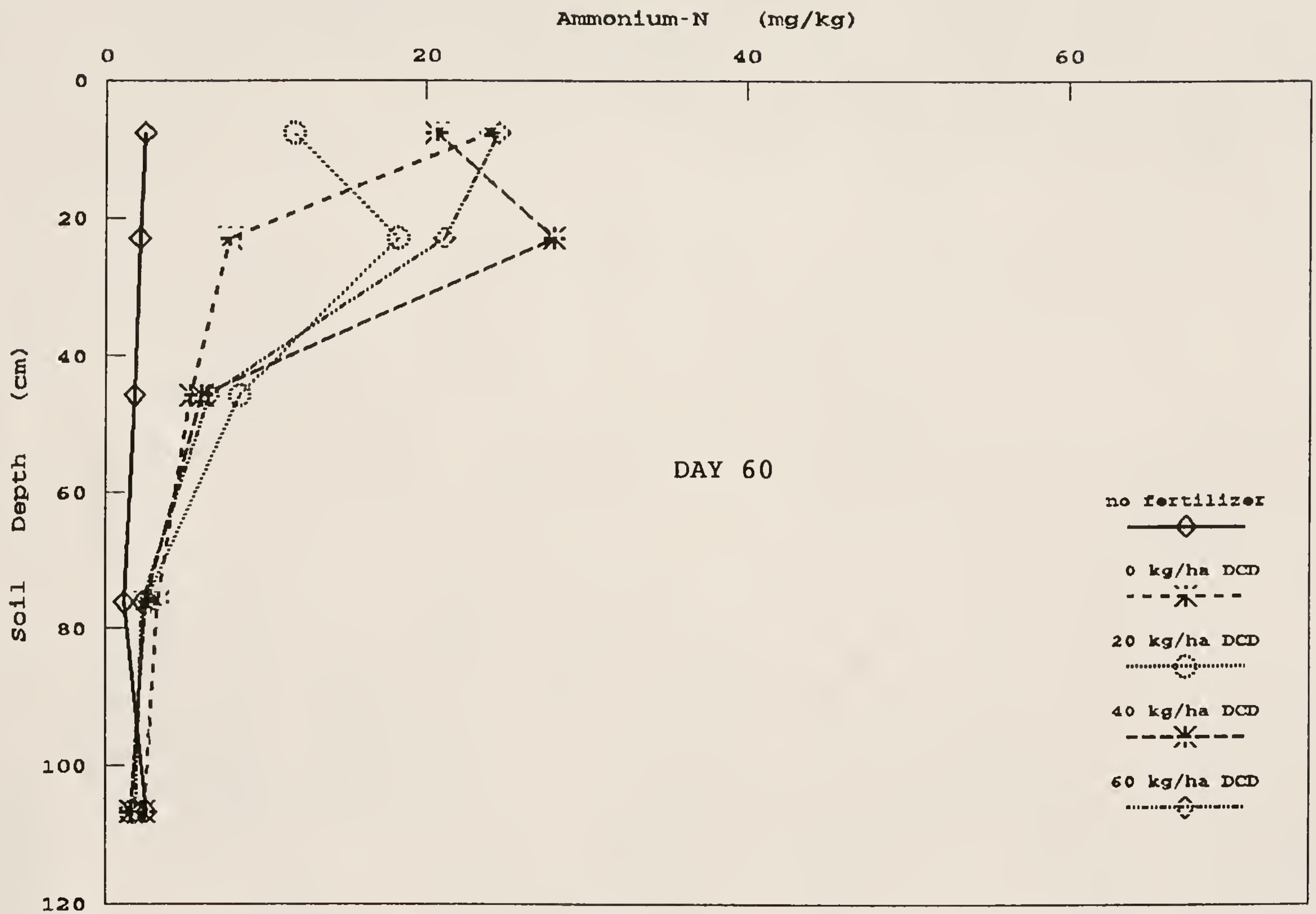

Figure 6-4. Effects of DCD rate on soil NH_4^+-N concentration with depth 60 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

On day 81, soil NH_4^+-N concentration (Figure 6-5) increased with an increase in DCD rate at the 61 to 91 and 91 to 122 cm depths. At the 61 to 91 cm depth, an increase in DCD rate from 0 to 20 kg ha^{-1} had no effect on soil NH_4^+-N concentration. With an increase in DCD rate from 20 to 40 kg ha^{-1}, soil NH_4^+-N concentration decreased from 2.7 to 2.0 mg kg^{-1}. With an increase in DCD rate to 60 kg ha^{-1}, soil NH_4^+-N concentration increased from 2.0 to 4.0 mg kg^{-1}, which was higher than that with 0 DCD. At the 91 to 122 cm depth, soil NH_4^+-N concentration increased from 2.2 to 3.1 mg kg^{-1} with an increase in DCD rate from 0 to 60 kg ha^{-1}. On day 116 (Figure 6-6) soil NH_4^+-N concentration was not influenced by DCD rate (Table 6-1).

Soil NH_4^+-N concentration data for each of the five depths were converted from mg NH_4^+-N kg^{-1} of soil, to kg of NH_4^+-N ha^{-1}. The sum of these values was presented as the total kg NH_4^+-N ha^{-1} in the 1.22 m soil profile (Figure 6-7). This calculation assumed a soil specific gravity of 1.40 g cm^{-3} for the 0 to 15 cm depth, and 1.57 g cm^{-3} for the other depths, as reported for this soil series (USDA, 1983).

On day 14, quantities of total kg NH_4^+-N ha^{-1} in the 1.22 m profile were 307, 485, 275, and 332 kg ha^{-1} with DCD rates of 0, 20, 40, and 60 kg ha^{-1}, respectively. On day 31, quantities of total kg NH_4^+-N ha^{-1} in the profile were 167, 286, 159, and 222 kg ha^{-1} with DCD rates of 0, 20, 40, and 60 kg ha^{-1}, respectively. On days 14 and 31, quantities

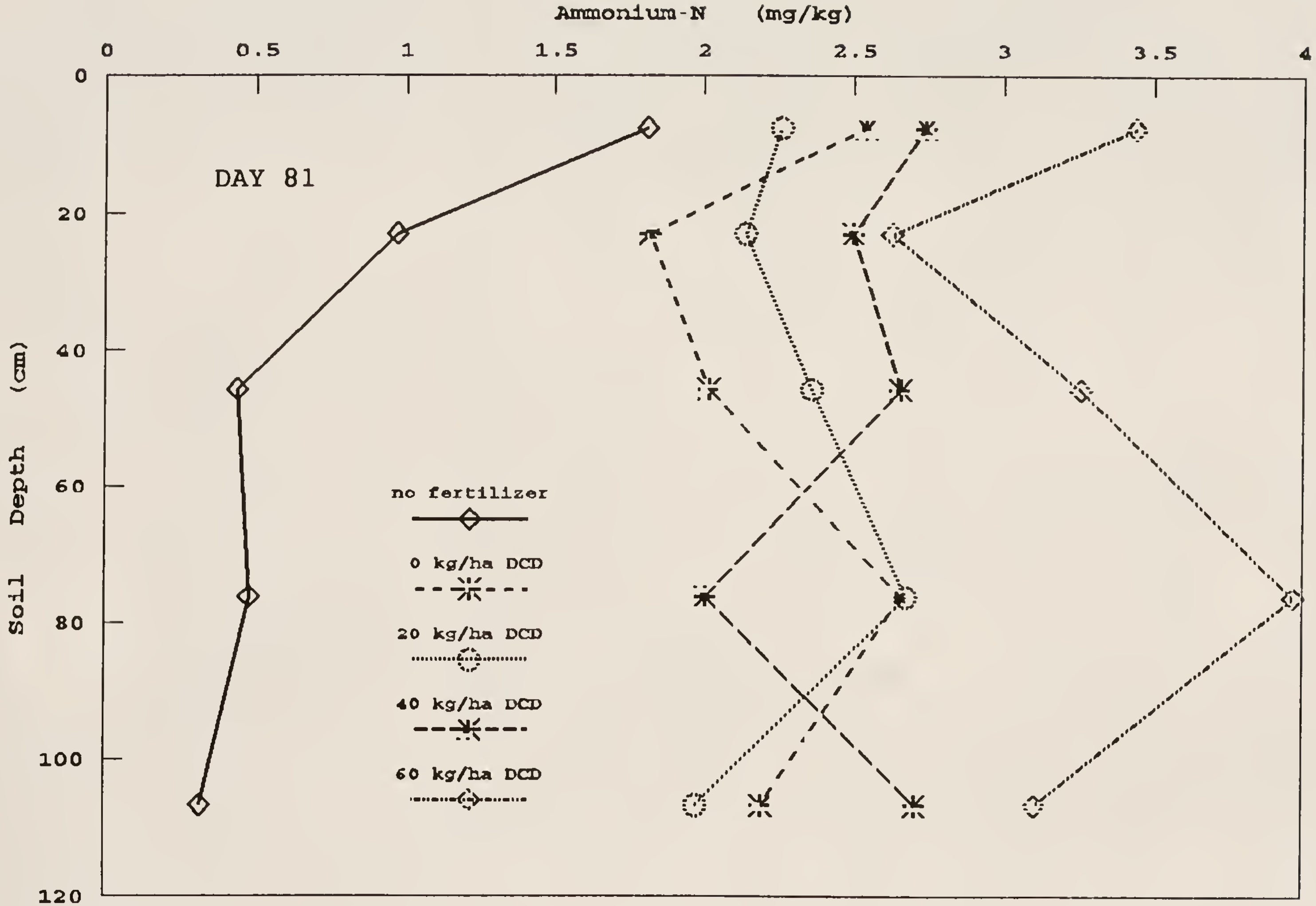

Figure 6-5. Effects of DCD rate on soil NH_4^+-N concentration with depth 81 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

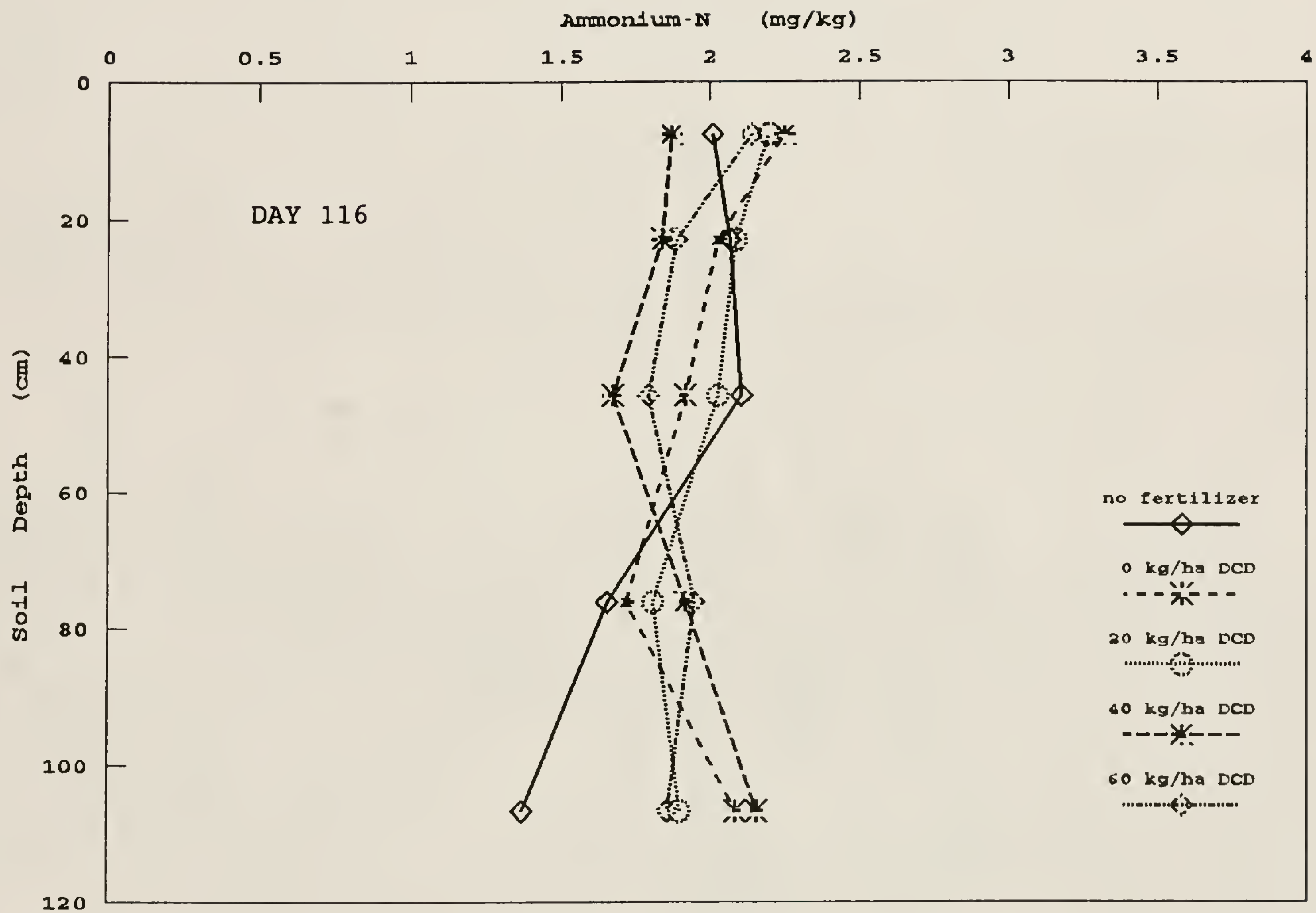

Figure 6-6. Effects of DCD rate on soil NH_4^+-N concentration with depth 116 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

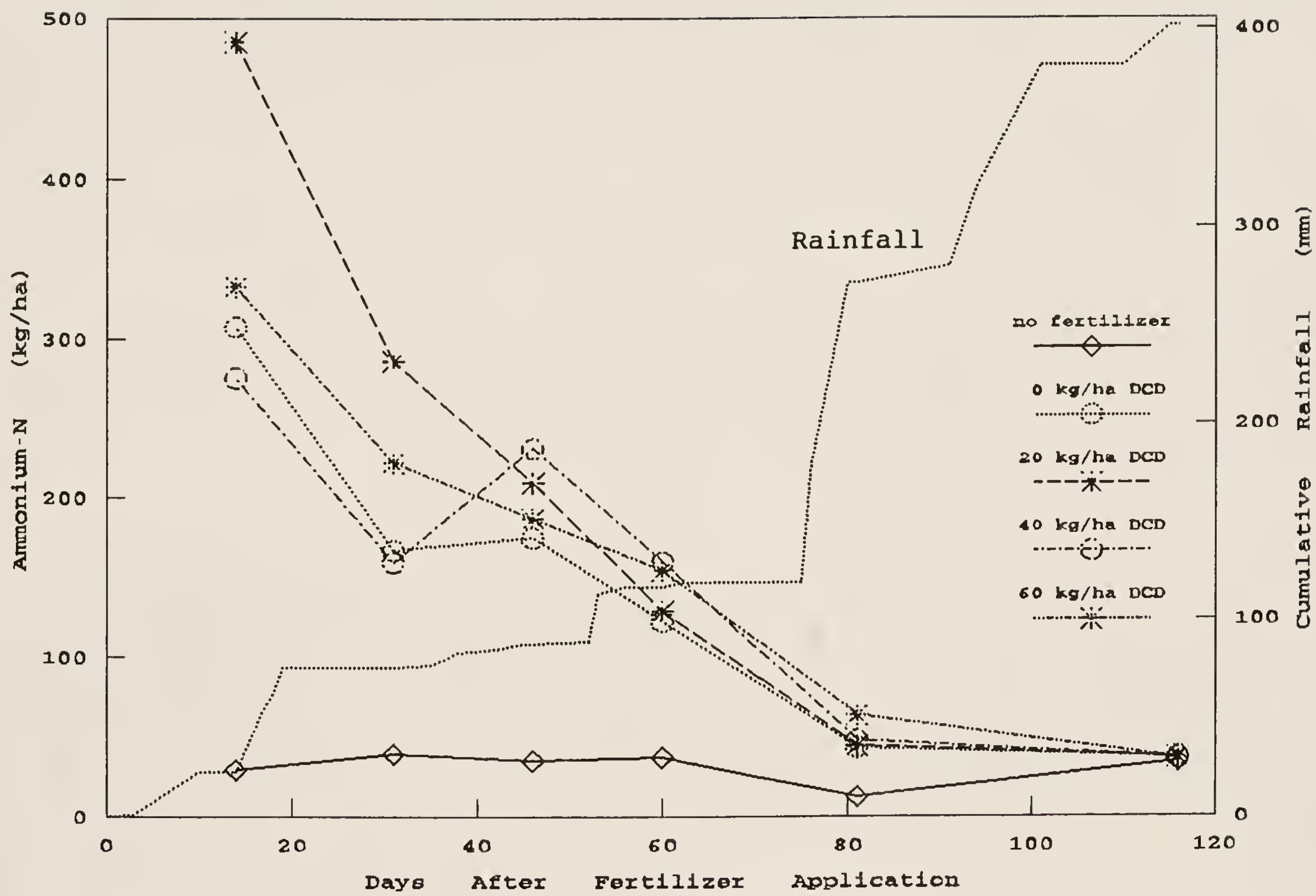

Figure 6-7. Effects of DCD rate on soil NH_4^+-N in the 1.22 m profile of a fallow Quartzipsamment at Live Oak.

of total soil NH_4^+-N with 60 kg ha^{-1} DCD were not different from those with 0 DCD because DCD rate effects were cubic (Table 6-1).

On day 81, total NH_4^+-N in the 1.22 m profile increased from 43 to 63 kg ha^{-1} with an increase in DCD rate from 0 to 60 kg ha^{-1} (Table 6-1). Total NH_4^+-N in the 1.22 m profile was not influenced by DCD rate on days 46, 60, or 116.

Soil NO_3^--N

On day 14, soil NO_3^--N concentrations at the 0 to 15, 15 to 30, and 61 to 91 cm depths, decreased with an increase in DCD rate from 0 to 60 kg ha^{-1} (Figure 6-8 and Table 6-2). These decreases were from 10.7 to 4.6, 4.7 to 3.2, and 2.3 to 1.3 mg kg^{-1} at the 0 to 15, 15 to 30, and 61 to 91 cm depths, respectively.

On day 31 at all depths, soil NO_3^--N concentrations were reduced with increases in DCD rate (Figure 6-9 and Table 6-2). At the 0 to 15 cm depth, soil NO_3^--N concentration decreased from 43 to 11 mg kg^{-1} with an increase in DCD rate from 0 to 40 kg ha^{-1}. A further increase in DCD rate to 60 kg ha^{-1} had no effect at the 0 to 15 cm depth. With an increase in DCD rate from 0 to 60 kg ha^{-1}, soil NO_3^--N concentrations decreased from 13 to 3.8, 3.7 to 1.9, 2.3 to 1.3, and 1.9 to 1.1 mg kg^{-1} at the 15 to 30, 30 to 61, 61 to 91, and 91 to 122 cm depths, respectively.

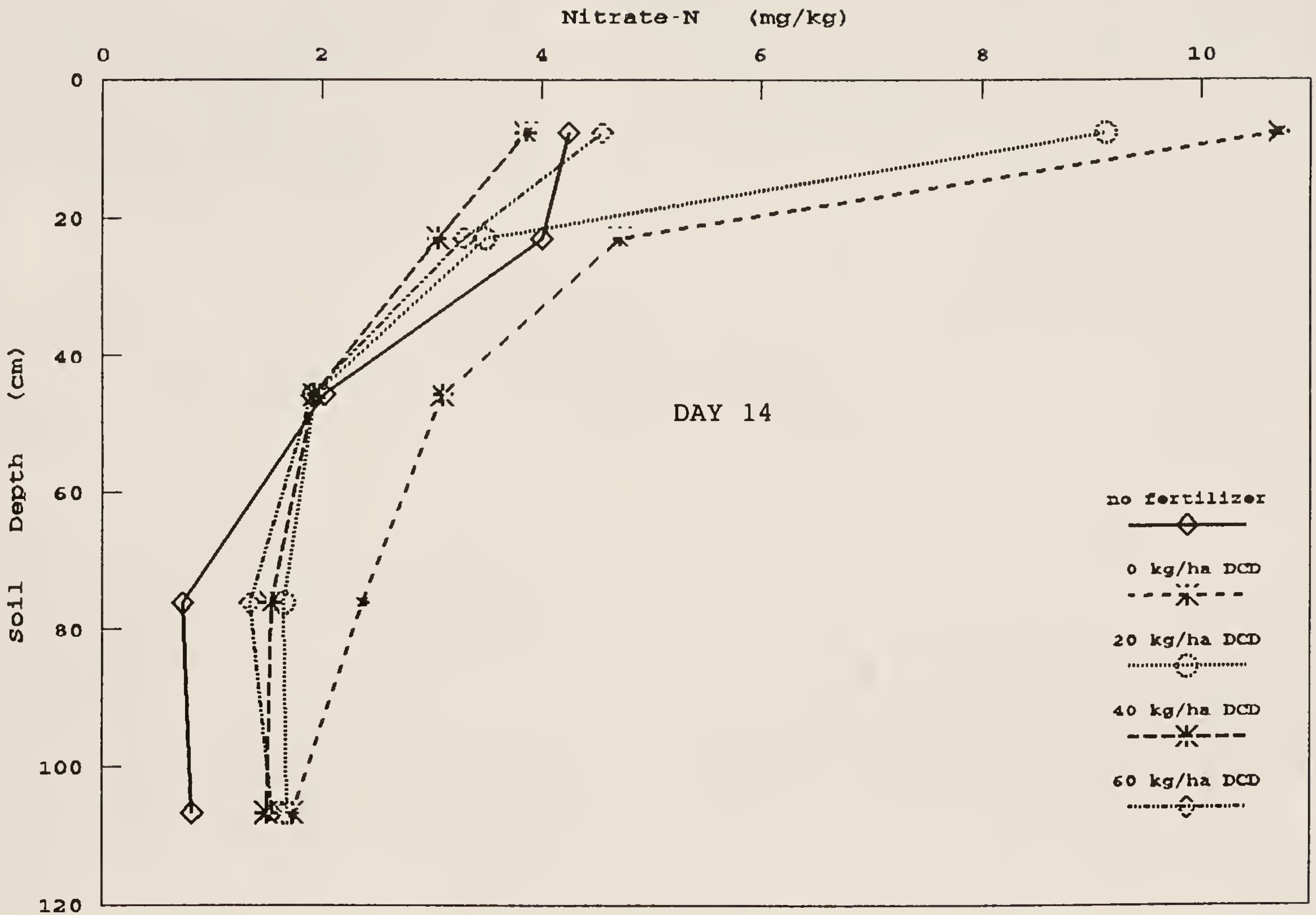

Figure 6-8. Effects of DCD rate on soil NO_3^--N concentration with depth 14 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

Table 6-2. Effects of DCD rate on soil NO_3^--N concentration at five depths over six sampling dates in a Quartzipsamment at Live Oak.

	Days After Fertilizer Application					
Depth (cm)	14	31	46	60	81	116
0-15	L**	L*** Q**	L*	NS	NS	NS
15-30	Lx	L** Q*	L**	NS	NS	NS
30-61	NS	L**	L*	L*	NS	Lx
61-91	L*	Lx	Lx	L*	NS	NS
91-122	NS	L*	NS	L*	NS	NS
Profile	L**	L*** Q**	L**	L*	NS	NS

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

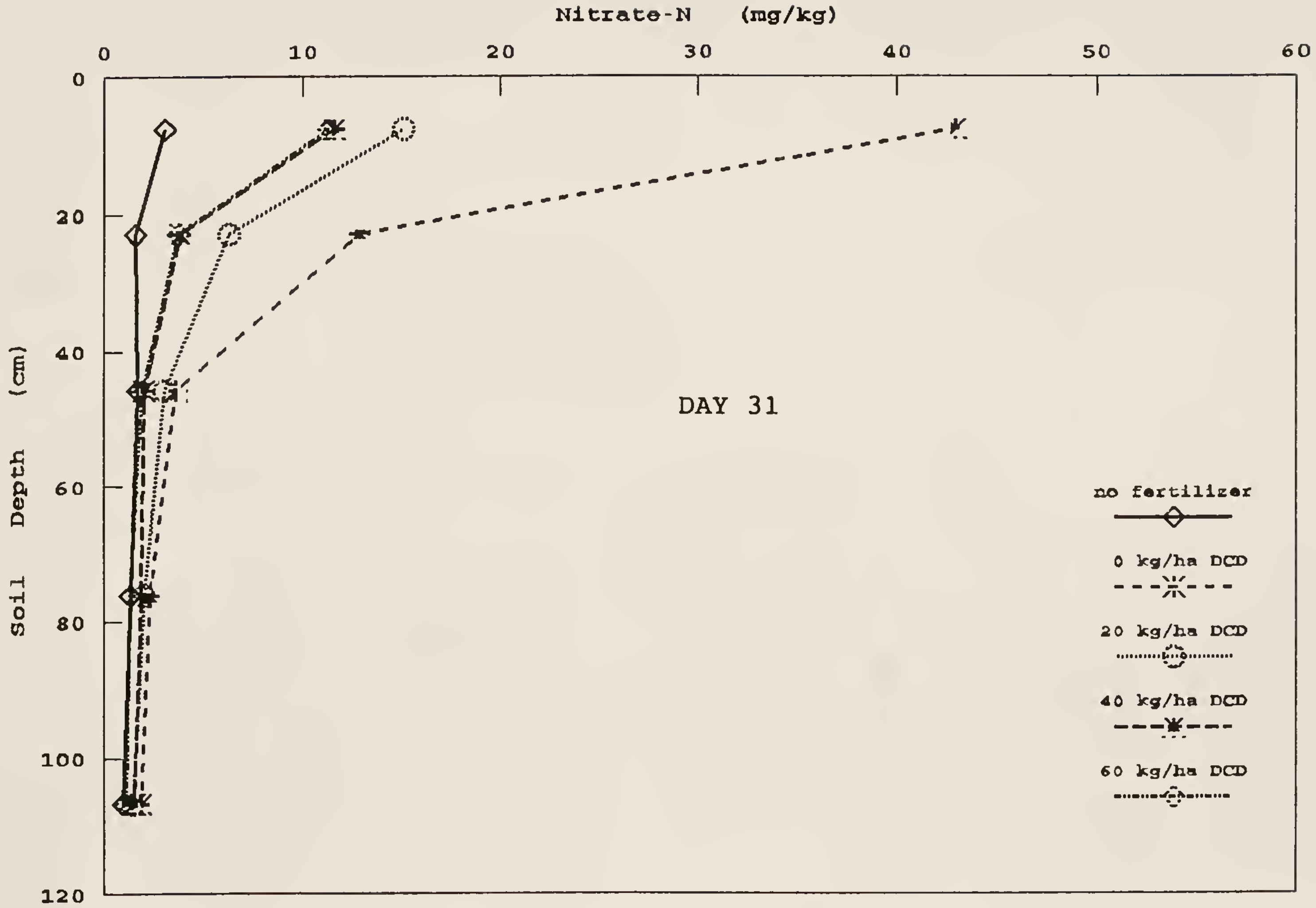

Figure 6-9. Effects of DCD rate on soil NO_3^--N concentration with depth 31 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

On day 46, soil NO_3^--N concentrations decreased with increases in DCD rate at all but the deepest (91 to 122 cm) depth (Figure 6-10 and Table 6-2). At the 0 to 15 cm depth, soil NO_3^--N concentration decreased from 60 to 34 mg kg^{-1} with an increase in DCD rate from 0 to 60 kg ha^{-1}. At the 15 to 30 cm depth, soil NO_3^--N concentration decreased from 35 to 16 mg kg^{-1} with an increase in DCD rate from 0 to 20 kg ha^{-1}. Further increases in DCD rate had no effect on soil NO_3^--N concentration at the 15 to 30 cm depth. With an increase in DCD rate from 0 to 60 kg ha^{-1}, soil NO_3^--N concentrations decreased from 7.4 to 4.0 and 3.1 to 2.1 mg kg^{-1} at the 30 to 61 and 61 to 91 cm depths, respectively.

On day 60 (Figure 6-11), soil NO_3^--N concentrations decreased with an increase in DCD rate at the 30 to 61, 61 to 91, and 91 to 122 depths (Table 6-2). These decreases in soil NO_3^--N concentration were from 26 to 17, 13 to 5.3, and 5.9 to 2.2 mg kg^{-1} at the 30 to 61, 61 to 91, and 91 to 122 depths, respectively.

On day 81 (Figure 6-12), soil NO_3^--N concentrations were not influenced by DCD rate at any depth (Table 6-2). On day 116 (Figure 6-13) at the 30 to 61 cm depth, soil NO_3^--N concentration increased from 2.0 to 2.7 mg kg^{-1} with an increase in DCD rate from 0 to 60 kg ha^{-1}.

As with the NH_4^+-N data, soil NO_3^--N concentrations for all five depths were transformed to kg ha^{-1} of NO_3^--N and summed to calculate the total kg NO_3^--N ha^{-1} in the 1.22 m

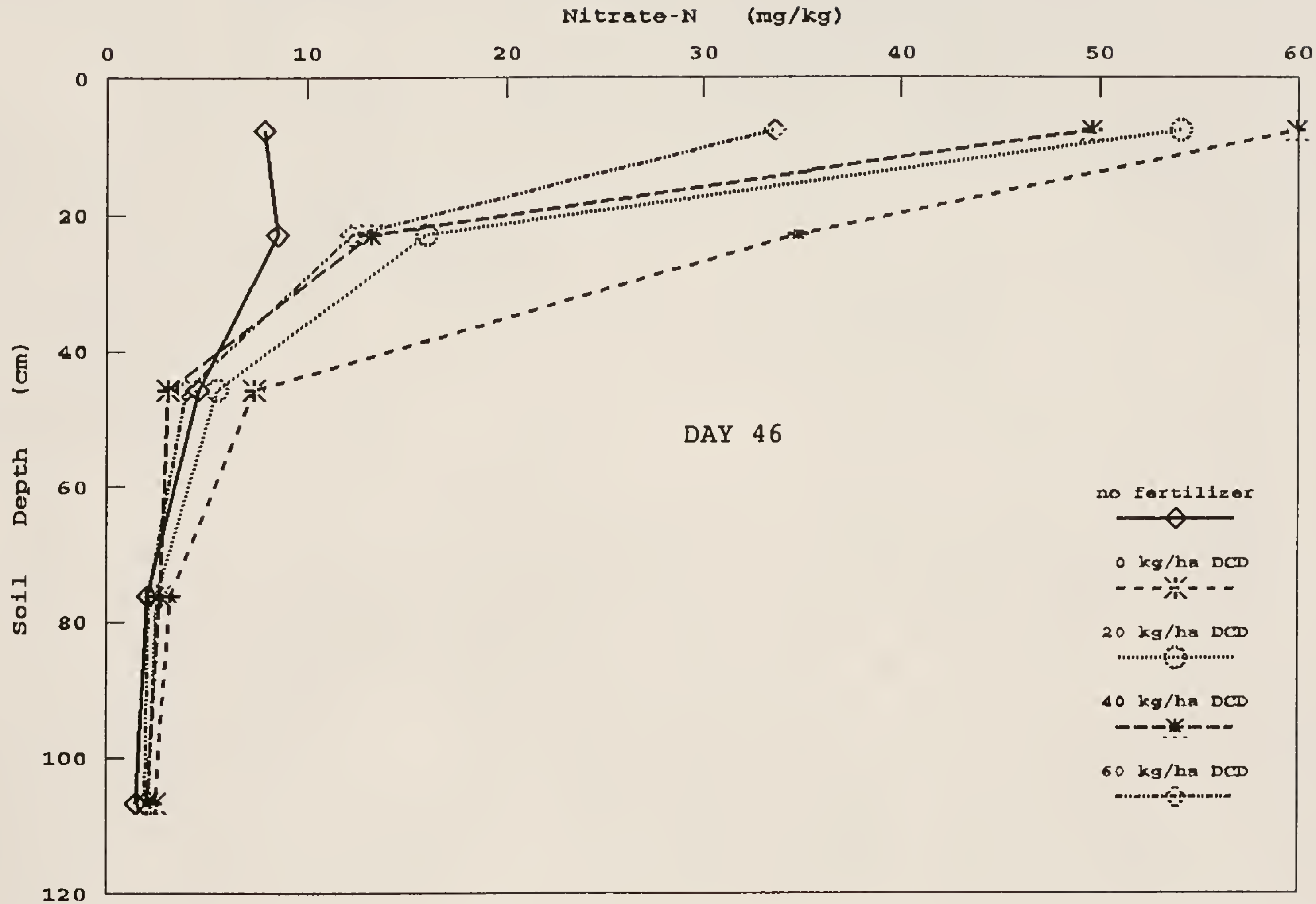

Figure 6-10. Effects of DCD rate on soil NO_3^--N concentration with depth 46 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

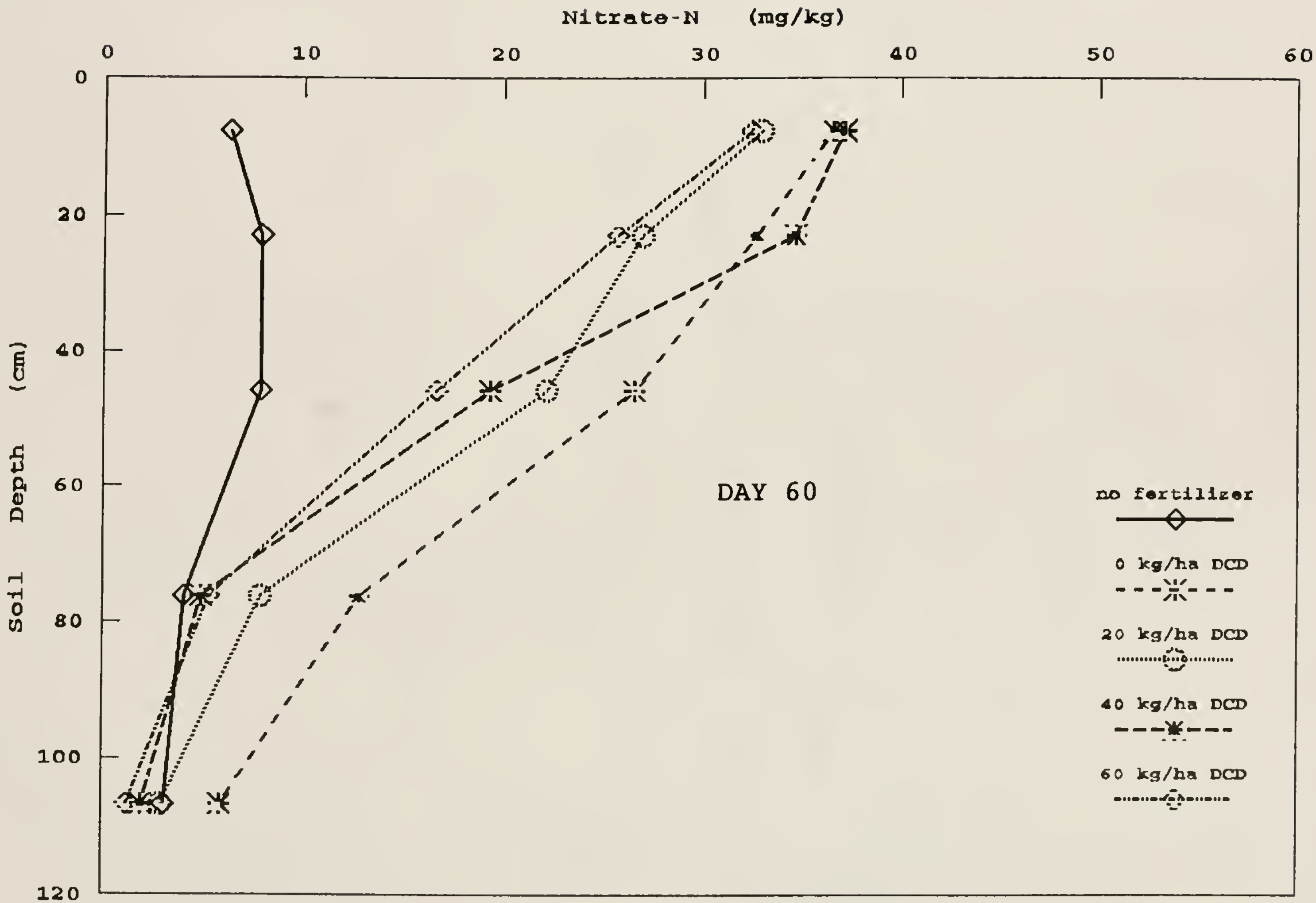

Figure 6-11. Effects of DCD rate on soil NO_3^--N concentration with depth 60 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

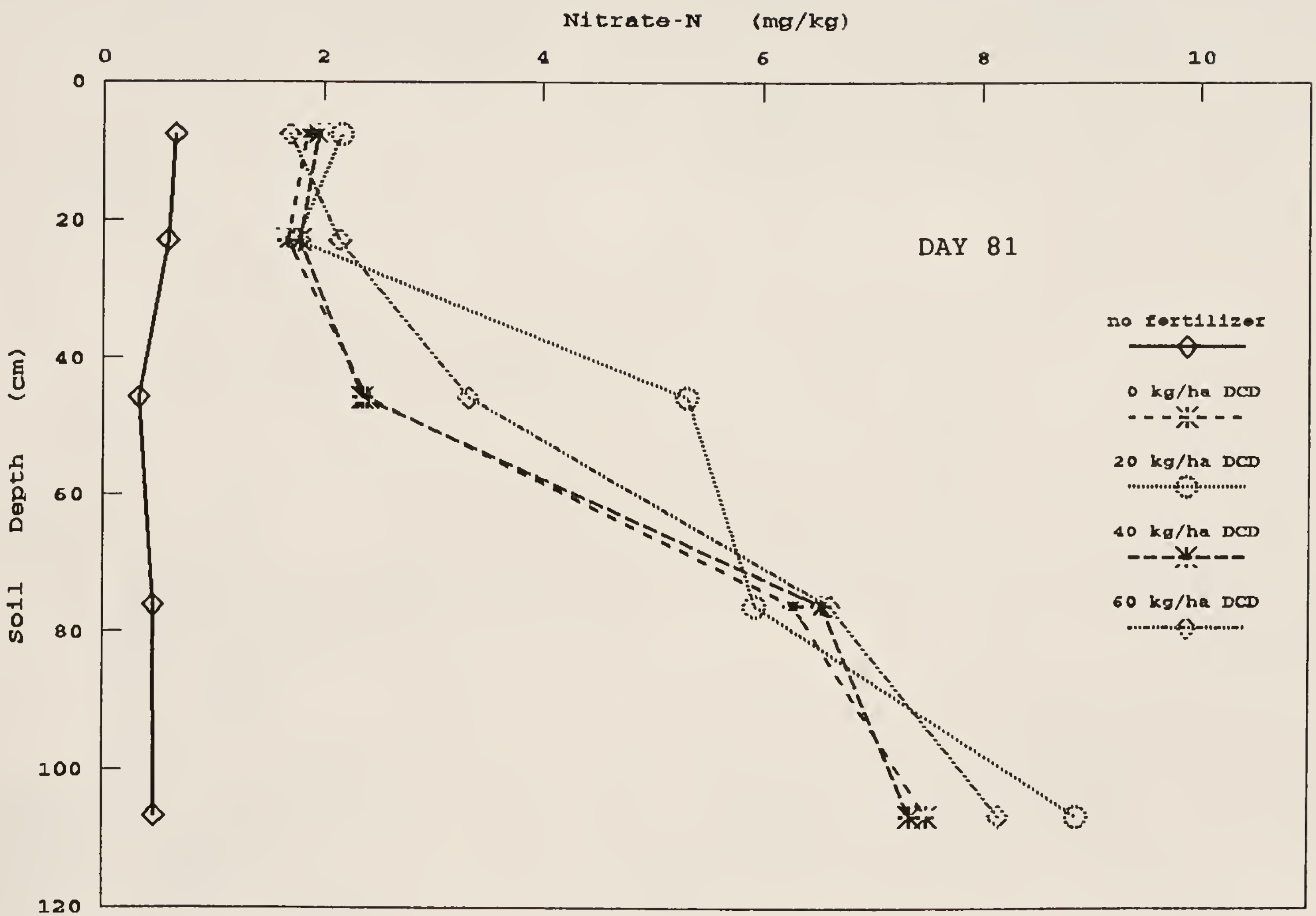

Figure 6-12. Effects of DCD rate on soil NO_3^--N concentration with depth 81 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

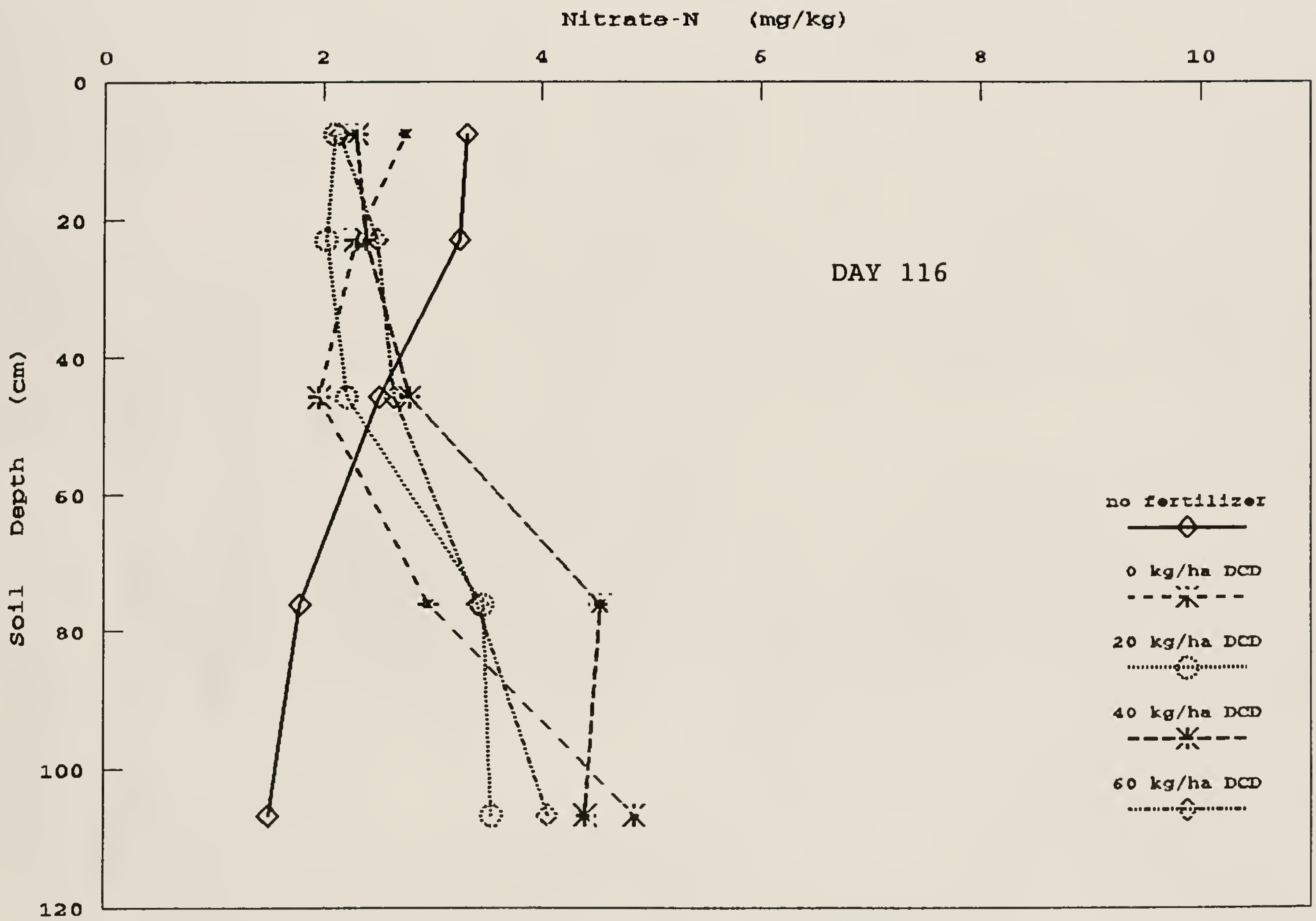

Figure 6-13. Effects of DCD rate on soil NO_3^--N concentration with depth 116 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

profile (Figure 6-14). Total NO_3^--N in the profile decreased with increases in DCD rate on days 14, 31, 46, and 60 (Table 6-2). On day 14, total NO_3^--N decreased from 67 to 40 kg ha^{-1} with an increase in DCD rate from 0 to 60 kg ha^{-1}. On day 31, total NO_3^--N decreased from 160 to 78 kg ha^{-1} with an increase in DCD rate from 0 to 20 kg ha^{-1}. With further increases in DCD rate, total NO_3^--N decreased to 54 kg ha^{-1}. With an increase in DCD rate from 0 to 60 kg ha^{-1}, total NO_3^--N in the profile decreased from 273 to 139 and from 373 to 247 kg ha^{-1} on days 46 and 60, respectively. On days 81 and 116, total NO_3^--N in the 1.22 m profile was not influenced by DCD rate.

Total Soil Inorganic N

Total soil NH_4^+-N and NO_3^--N (SIN) concentrations decreased with increases in DCD rate at several depths on days 14, 31, 46, and 60. On day 14 at the 61 to 91 cm depth, SIN concentration decreased (Figure 6-15 and Table 6-3) from 5.0 to 3.0 mg kg^{-1} with an increase in DCD rate from 0 to 60 kg ha^{-1}. On day 31, SIN concentrations (Figure 6-16 and Table 6-3) decreased from 35 to 18 and 4.0 to 2.8 mg kg^{-1} at the 15 to 30 and 91 to 122 cm depths, respectively.

On day 46, SIN concentrations (Figure 6-17) decreased from 59 to 32 and 11.7 to 8.0 mg kg^{-1} at the 15 to 30 and 30 to 61 cm depths, respectively, with an increase in DCD rate from 0 to 60 kg ha^{-1}. On day 60 (Figure 6-18), with an

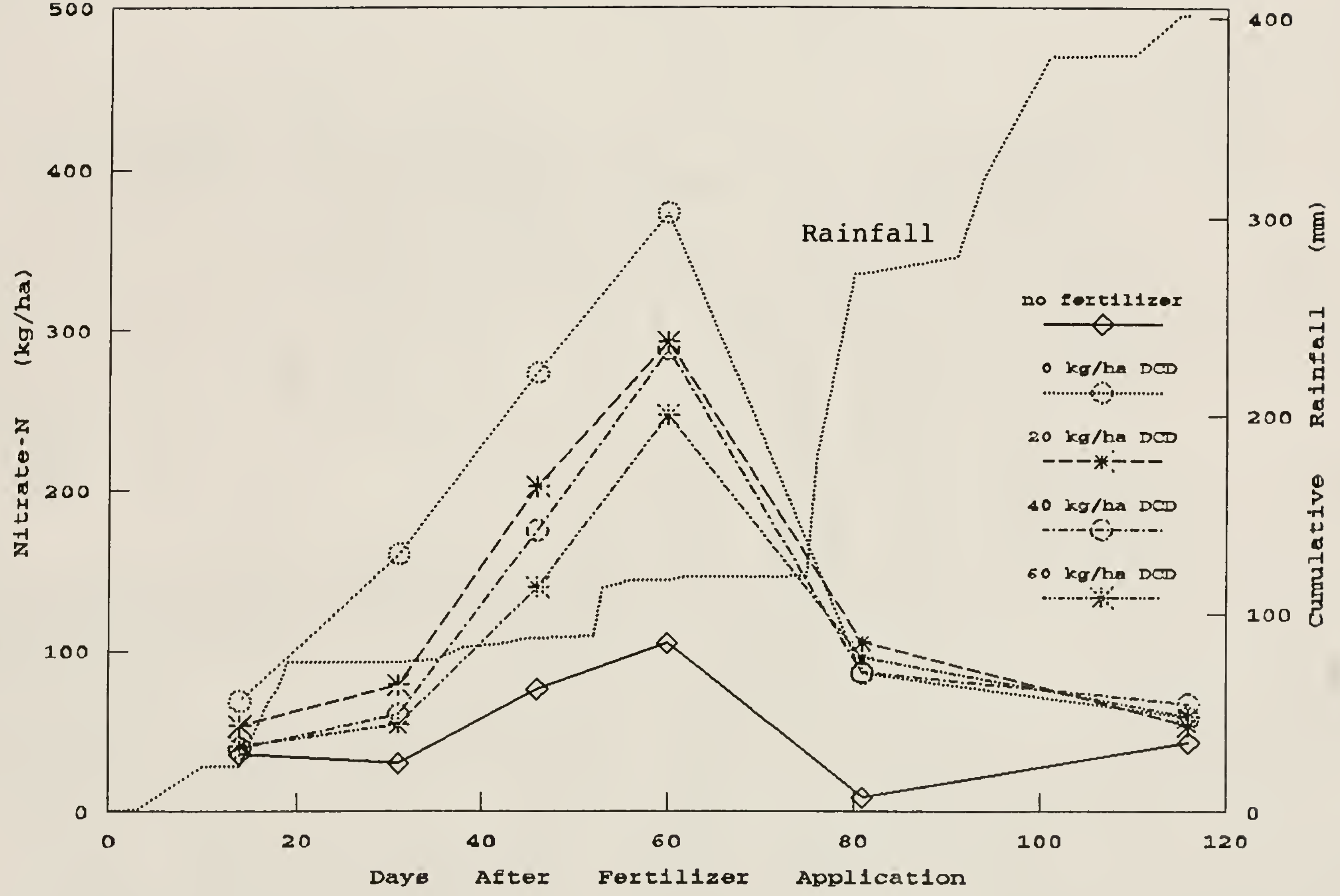

Figure 6-14. Effects of DCD rate on soil NO_3^--N in the 1.22 m profile of a fallow Quartzipsamment at Live Oak.

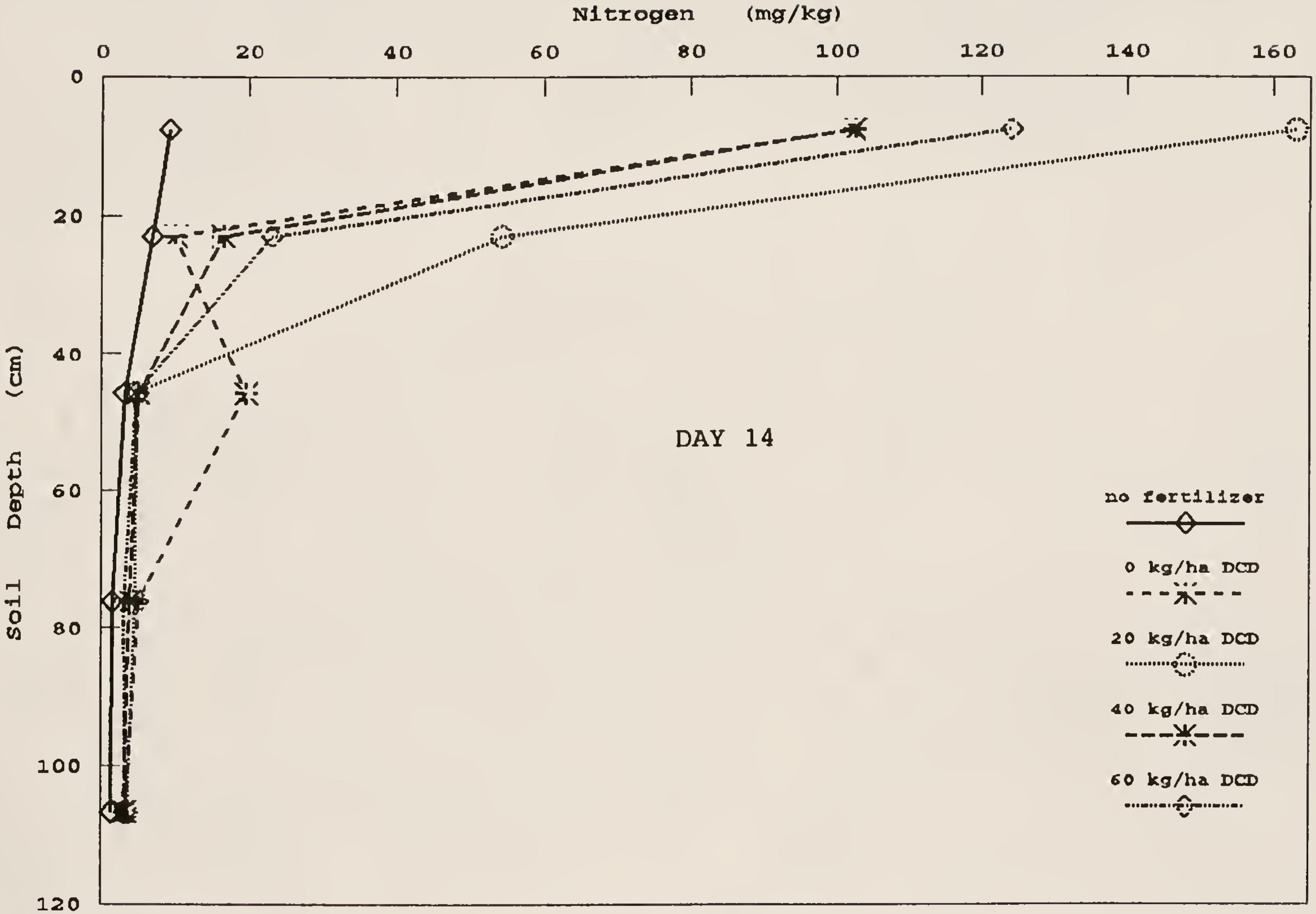

Figure 6-15. Effects of DCD rate on soil inorganic N (NH_4^+-N + NO_3^--N) concentration with depth 14 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

Table 6-3. Effects of DCD rate on soil inorganic N (NH_4^+-N + NO_3^--N) at five depths over six sampling dates in a Quartzipsamment at Live Oak.

	Days After Fertilizer Application					
Depth (cm)	14	31	46	60	81	116
0-15	NS	NS	NS	NS	NS	NS
15-30	NS	Lx	Lx	NS	L*	NS
30-61	NS	NS	L*	Lx	NS	NS
61-91	L*	NS	NS	L**	NS	NS
91-122	NS	L*	NS	L* Qx	NS	NS
Profile	Cx	Cx	NS	NS	NS	NS

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), or 0.01 (**) probability levels, respectively.

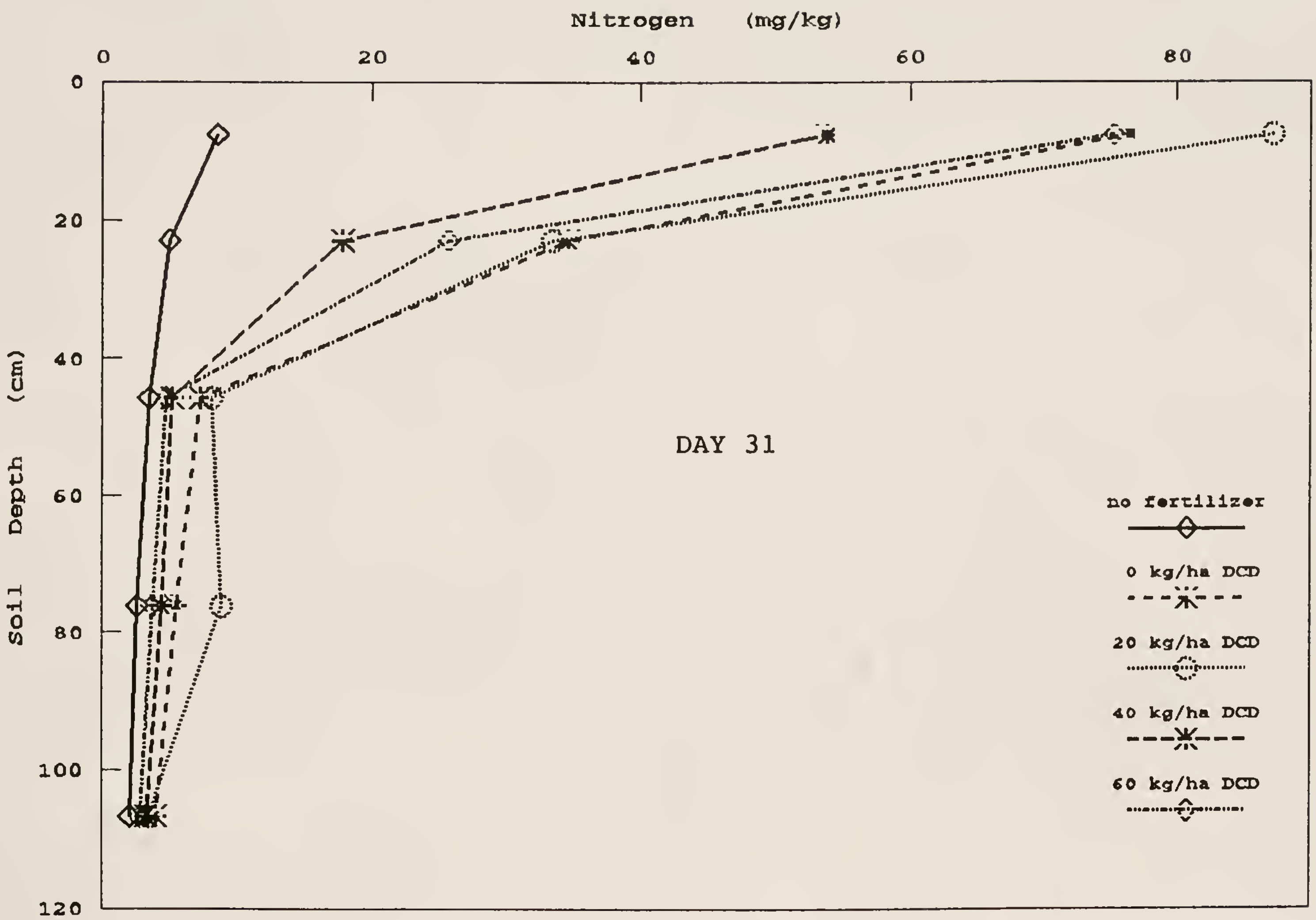

Figure 6-16. Effects of DCD rate on soil inorganic N (NH_4^+-N + NO_3^--N) concentration with depth 31 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

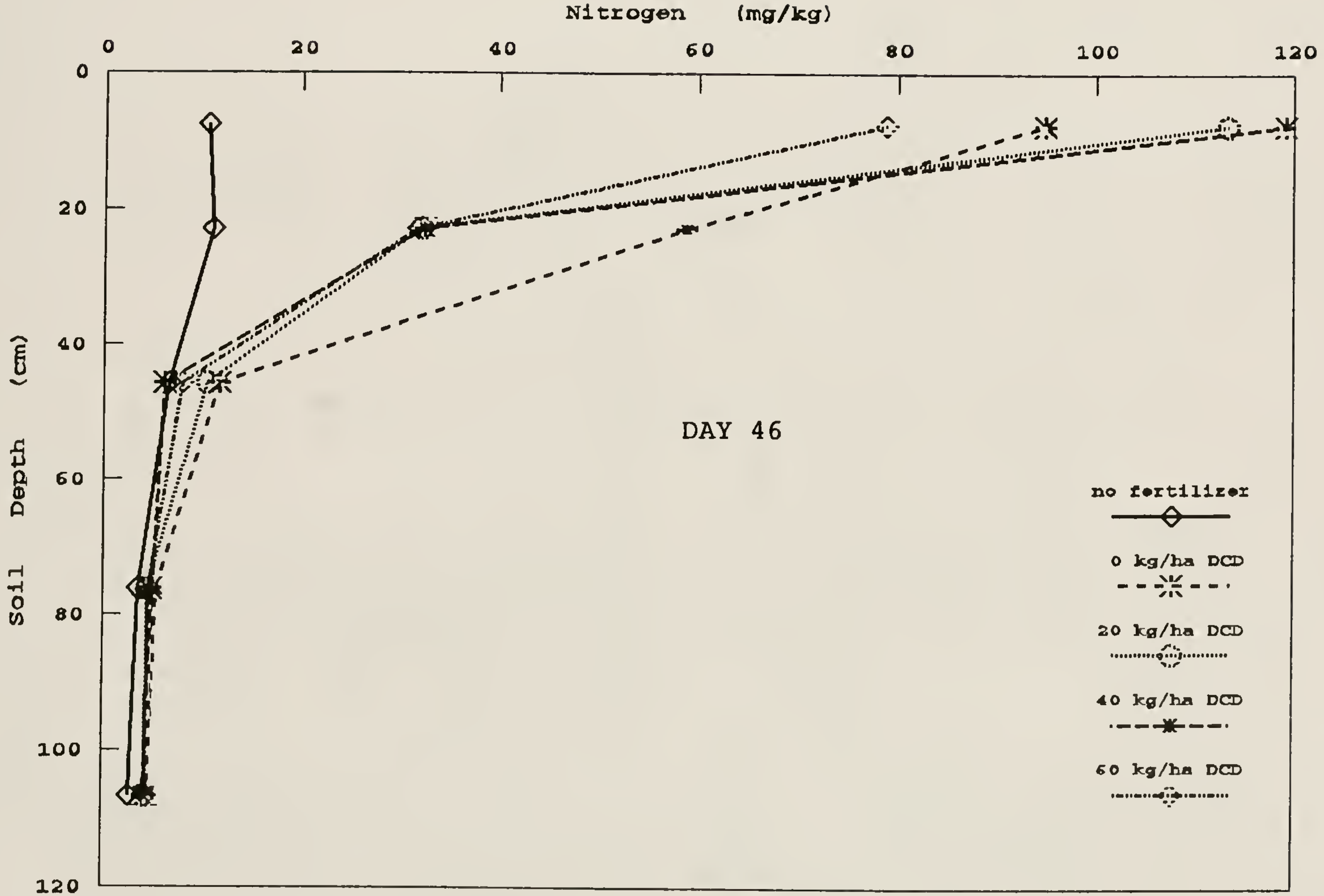

Figure 6-17. Effects of DCD rate on soil inorganic N (NH_4^+-N + NO_3^--N) concentration with depth 46 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

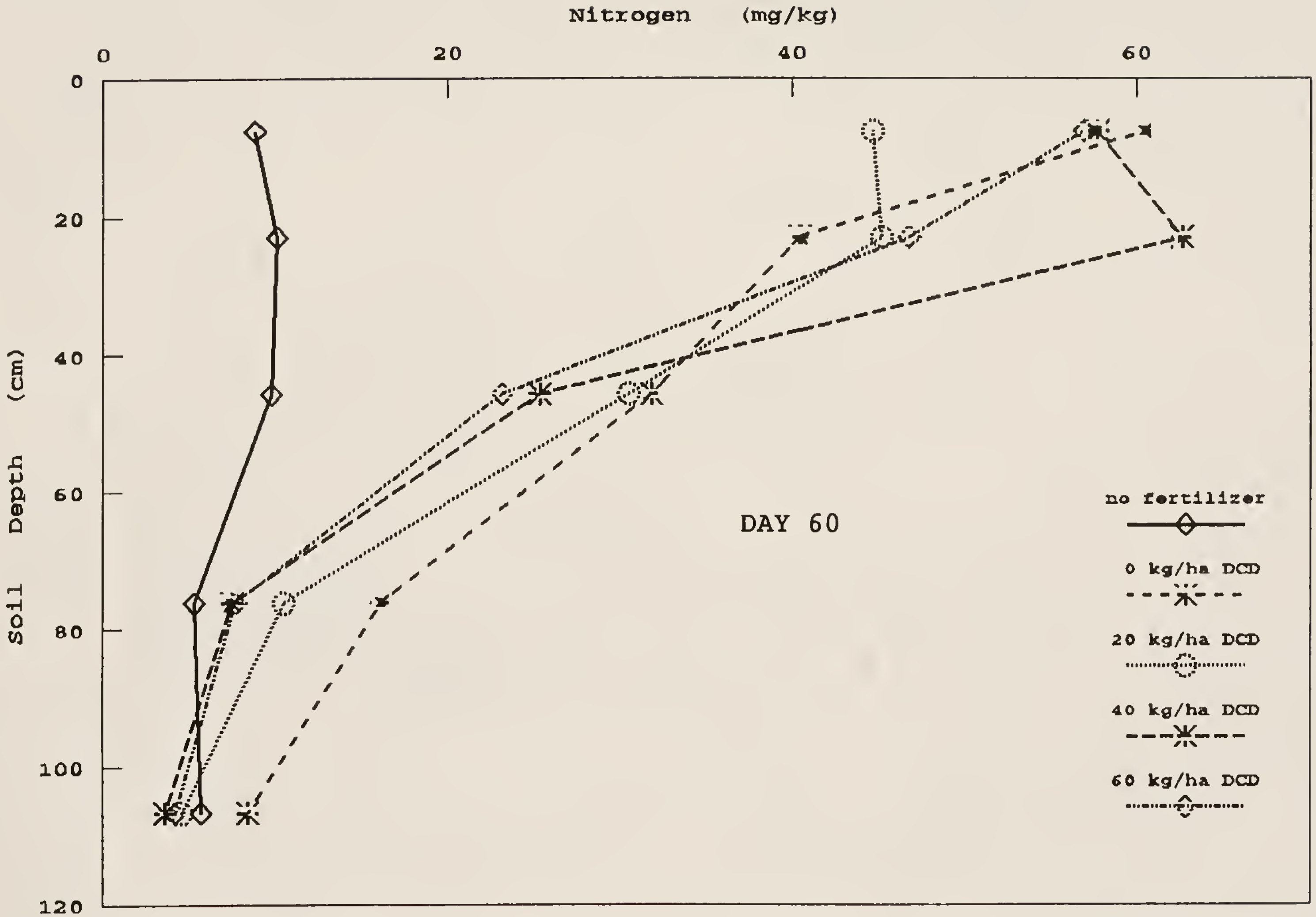

Figure 6-18. Effects of DCD rate on soil inorganic N (NH_4^+-N + NO_3^--N) concentration with depth 60 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

increase in DCD rate from 0 to 60 kg ha^{-1}, SIN concentrations decreased from 32 to 23, 16 to 7.5, and 8.3 to 4.1 mg kg^{-1} at the 30 to 61, 61 to 91, and 91 to 122 cm depths, respectively (Table 6-3).

The only instance where increases in DCD rate resulted in increased SIN concentration (from 3.5 to 4.8 mg kg^{-1}), was on day 81 at the 15 to 30 cm depth (Figure 6-19 and Table 6-3). On day 116, SIN concentrations were not influenced by DCD rate at any depth (Figure 6-20).

Again, these data were transformed to kg SIN ha^{-1} and summed for the 1.22 m profile (Figure 6-21). On days 14 and 41, DCD rate effects on total kg SIN ha^{-1} in the profile were cubic (Table 6-3). On day 14, quantities of total SIN in the profile were 376, 538, 315, and 373 kg ha^{-1} with 0, 20, 40, and 60 kg ha^{-1} DCD, respectively. On day 31, quantities of total SIN in the profile were 327, 364, 219, and 276 kg ha^{-1} with 0, 20, 40, and 60 kg ha^{-1} DCD, respectively. Total kg SIN ha^{-1} in the 1.2 m profile was not influenced by DCD rate on days 46, 60, 81 or 116.

Soil NO_3^--N/(NO_3^--N + NH_4^+-N) Ratio

The soil NO_3^--N concentration was divided by SIN concentration for each date-depth combination. This ratio has been referred to as the nitrification ratio (Lossaint and Roubert, 1964) and the nitrification rate (Sahrawat, 1980). Data derived from this equation gave some indication

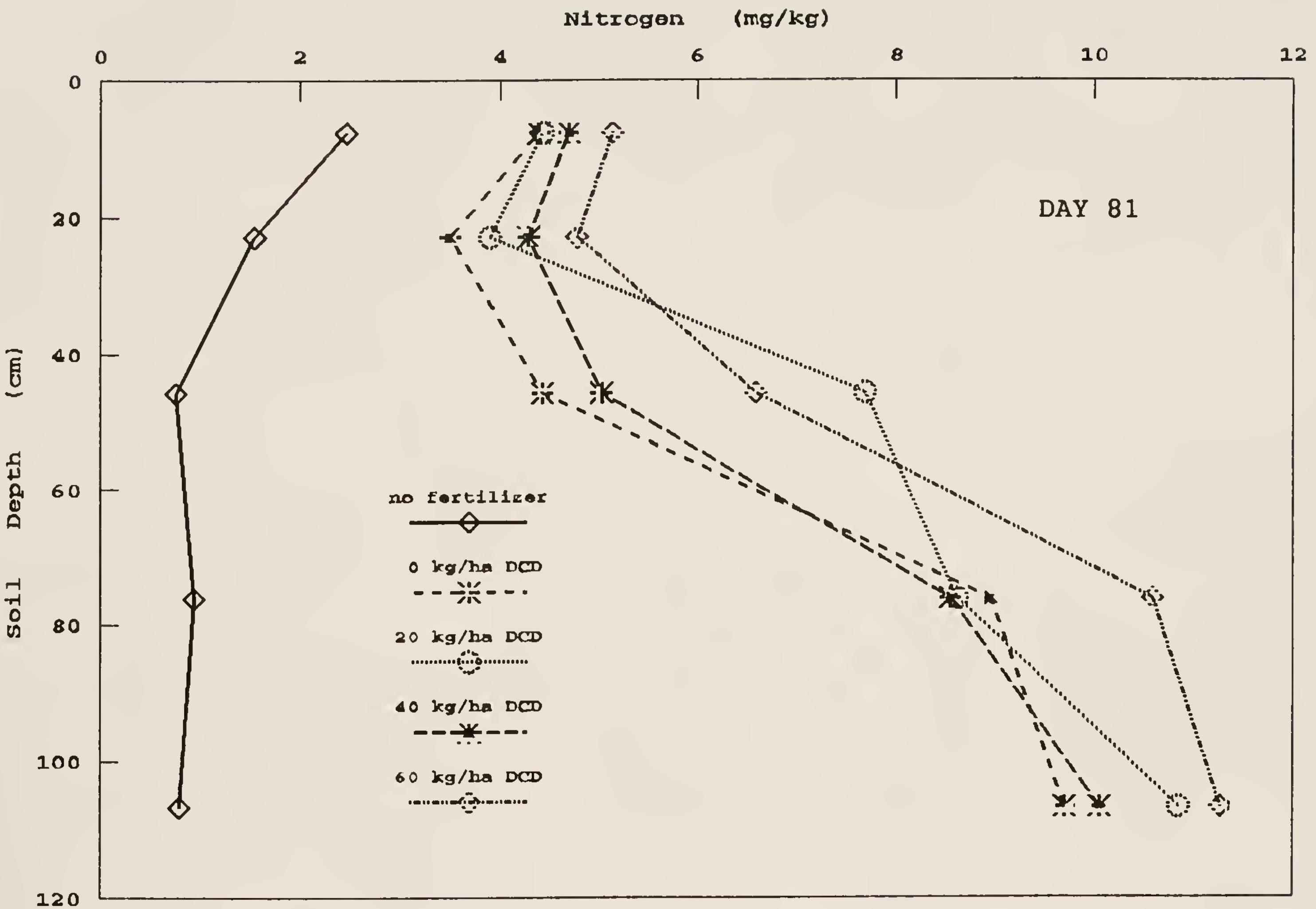

Figure 6-19. Effects of DCD rate on soil inorganic N (NH_4^+-N + NO_3^--N) concentration with depth 81 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

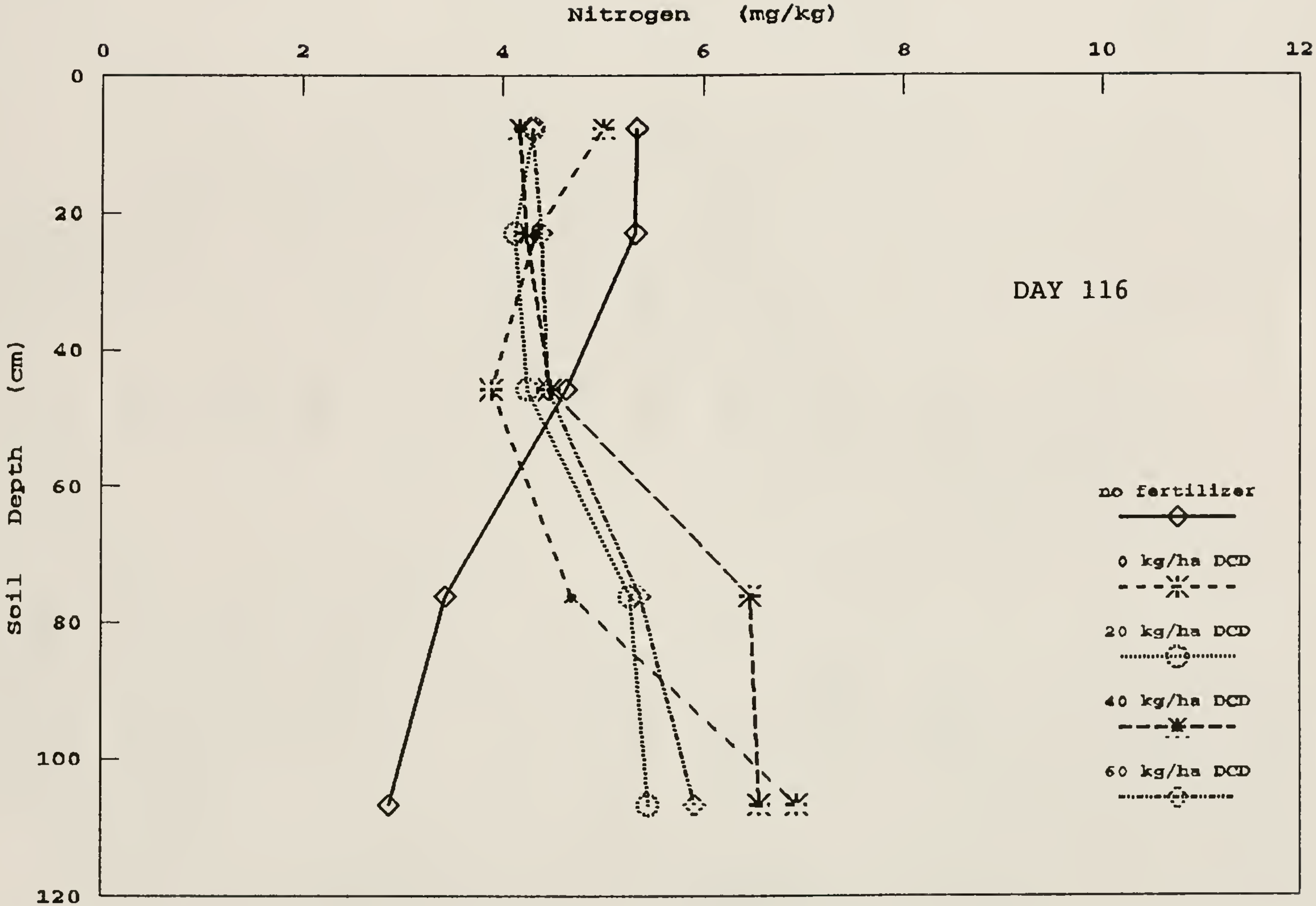

Figure 6-20. Effects of DCD rate on soil inorganic N (NH_4^+-N + NO_3^--N) concentration with depth 116 days after application of 200 kg N ha^{-1} to a fallow Quartzipsamment at Live Oak.

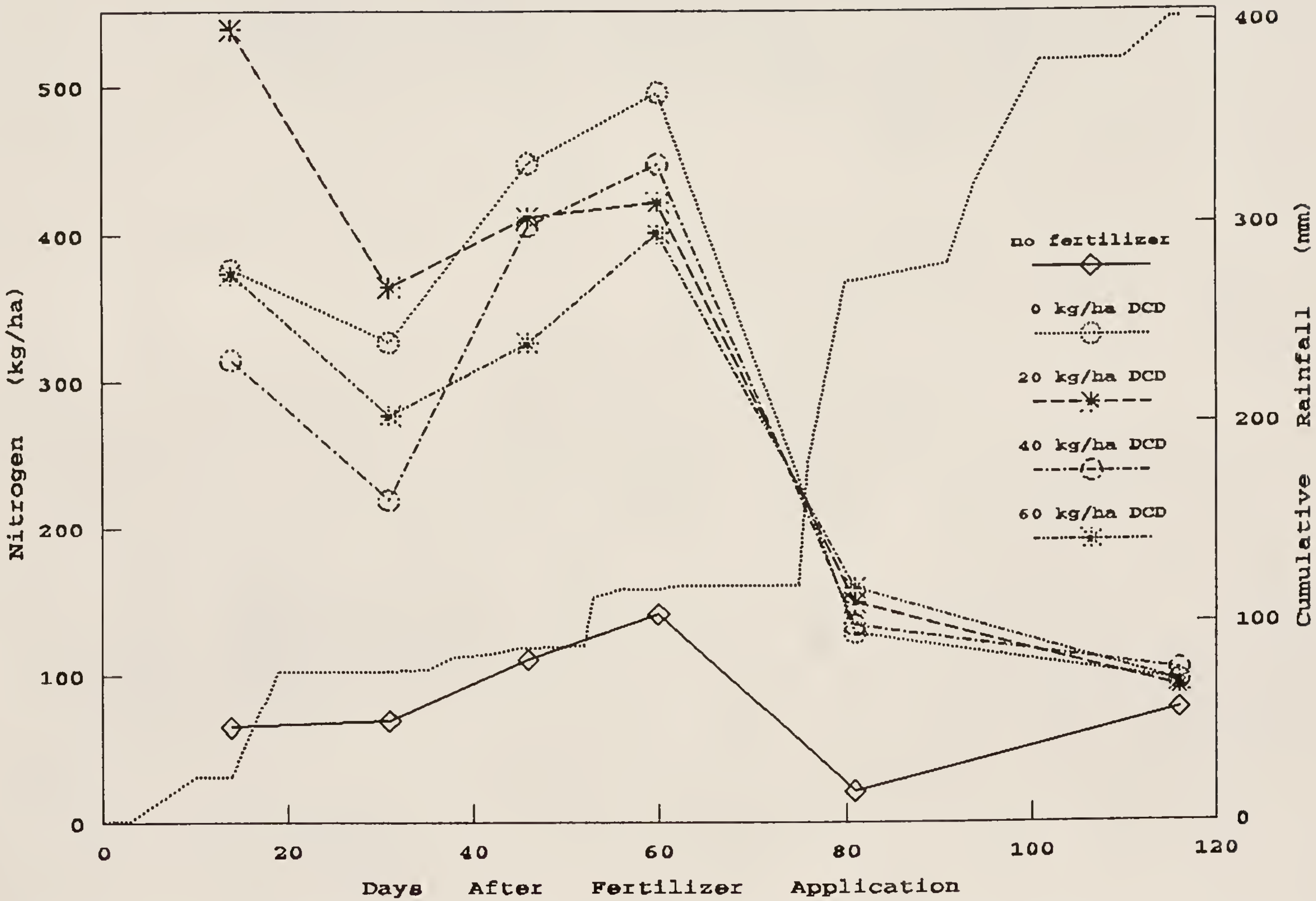

Figure 6-21. Effects of DCD rate on soil inorganic N (NH_4^+-N + NO_3^--N) in the 1.22 m profile of a fallow Quartzipsamment at Live Oak.

of the extent to which nitrification was inhibited by DCD. Inhibition of nitrification should lower the magnitude of this ratio. The means of these data are not shown but analysis of variance is shown in Table 6-4. The NO_3^--N/(NO_3^--N + NH_4^+-N) ratio decreased with increases in DCD rate on day 14 at the 0 to 15 and 15 to 30 cm depths. On day 31, this ratio decreased at the 0 to 15 and 15 to 30 cm depths with increasing DCD rate. On day 46, this ratio decreased with increases in DCD rate at all five depths. On day 60, this ratio decreased at the 0 to 15, 15 to 30, and 30 to 61 cm depths with increases in DCD rate. On day 81, this ratio decreased at the 0 to 15 and 30 to 61 cm depths with increases in DCD rate. The only increase in the NO_3^--N/(NO_3^--N + NH_4^+-N) ratio with increased DCD rate, occurred at the 30 to 61 cm depth on day 116.

The NO_3^--N/(NO_3^--N + NH_4^+-N) ratio for the entire 1.22 m profile (Figure 6-22), was computed from the total kg NO_3^--N and SIN ha^{-1} in the profile. On day 14, DCD rate had no effect on the NO_3^--N/(NO_3^--N + NH_4^+-N) ratio in the 1.22 m profile as a whole (Table 6-4). On days 31, 46, 60, and 81, the NO_3^--N/(NO_3^--N + NH_4^+-N) ratio in the profile decreased with an increase in DCD rate. On day 116, DCD rate had no effect on the NO_3^--N/(NO_3^--N + NH_4^+-N) ratio in the 1.22 m profile as a whole.

These data indicate that DCD had an inhibiting effect on nitrification throughout all or most of the 1.22 m

Table 6-4. Effects of DCD rate on soil NO_3^--N/(NO_3^--N + NH_4^+-N) ratio at five depths over six sampling dates in a Quartzipsamment at Live Oak.

	Days After Fertilizer Application					
Depth (cm)	14	31	46	60	81	116
0-15	L*	L*** Q*	L*	Lx	L* Qx	NS
15-30	L* Qx	L*** QxC*	L**	L** Q*	NS	NS
30-61	NS	NS	Lx	L*	L*	L*
61-91	NS	NS	Lx	NS	Qx	QxCx
91-122	NS	NS	Lx	NS	NS	NS
Profile	NS	L*** Q*C*	L*	L*	L**	NS

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

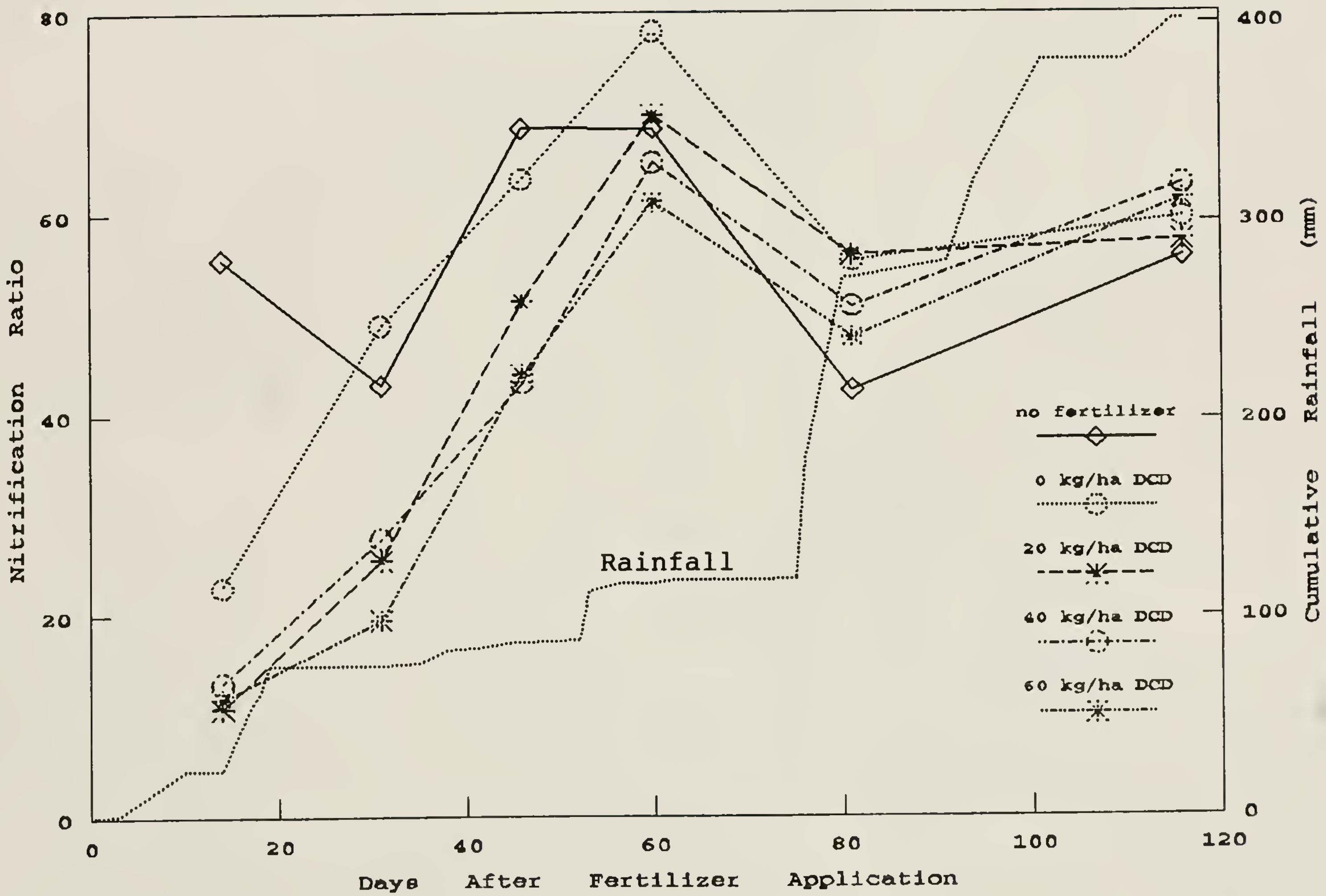

Figure 6-22. Effects of DCD rate on soil nitrification ratio, i.e., (NO_3^--N x 100/(NH_4^+-N + NH_3^--N) in the 1.22 m profile of a fallow Quartzipsamment at Live Oak.

profile from 31 to 81 days after urea and DCD application, and in at least portions of the profile from 14 to 81 days after application.

Soil DCD

Fourteen days after DCD application, soil DCD concentration increased with an increase in DCD rate from 20 to 60 kg ha^{-1} (Figure 6-23 and Table 6-5) at the 0 to 15, 15 to 30, and 61 to 91 cm depths. On day 31, soil DCD concentration increased with an increase in DCD rate (Figure 6-24) at the 0 to 15, and 15 to 30 cm depths. Similar DCD rate effects on soil DCD concentration were observed on day 46 (Figure 6-25) at the 15 to 30 and 61 to 91 cm depths, and on day 60 (Figure 6-26) at the 0 to 15 and 30 to 61 cm depths. Soil DCD concentration increased with increases in DCD rate on day 81 (Figure 6-27) at all but the 0 to 15 cm depth. On day 116 (Figure 6-28), soil DCD concentration increased with increases in DCD rate at the 61 to 91, and 91 to 122 cm depths. Total kg soil DCD ha^{-1} in the 1.22 m profile (Figure 6-29) increased with increases in DCD rate at all sampling dates (Table 6-5).

Based on these data, an estimate of the residence half time of DCD in the 1.22 m profile was calculated by means of regression. This calculation assumed the amounts of DCD applied as the points of origin on the X axis of Figure 6-29. Because of the shapes of the curves in Figure 6-29, these residence half times can only be considered rough

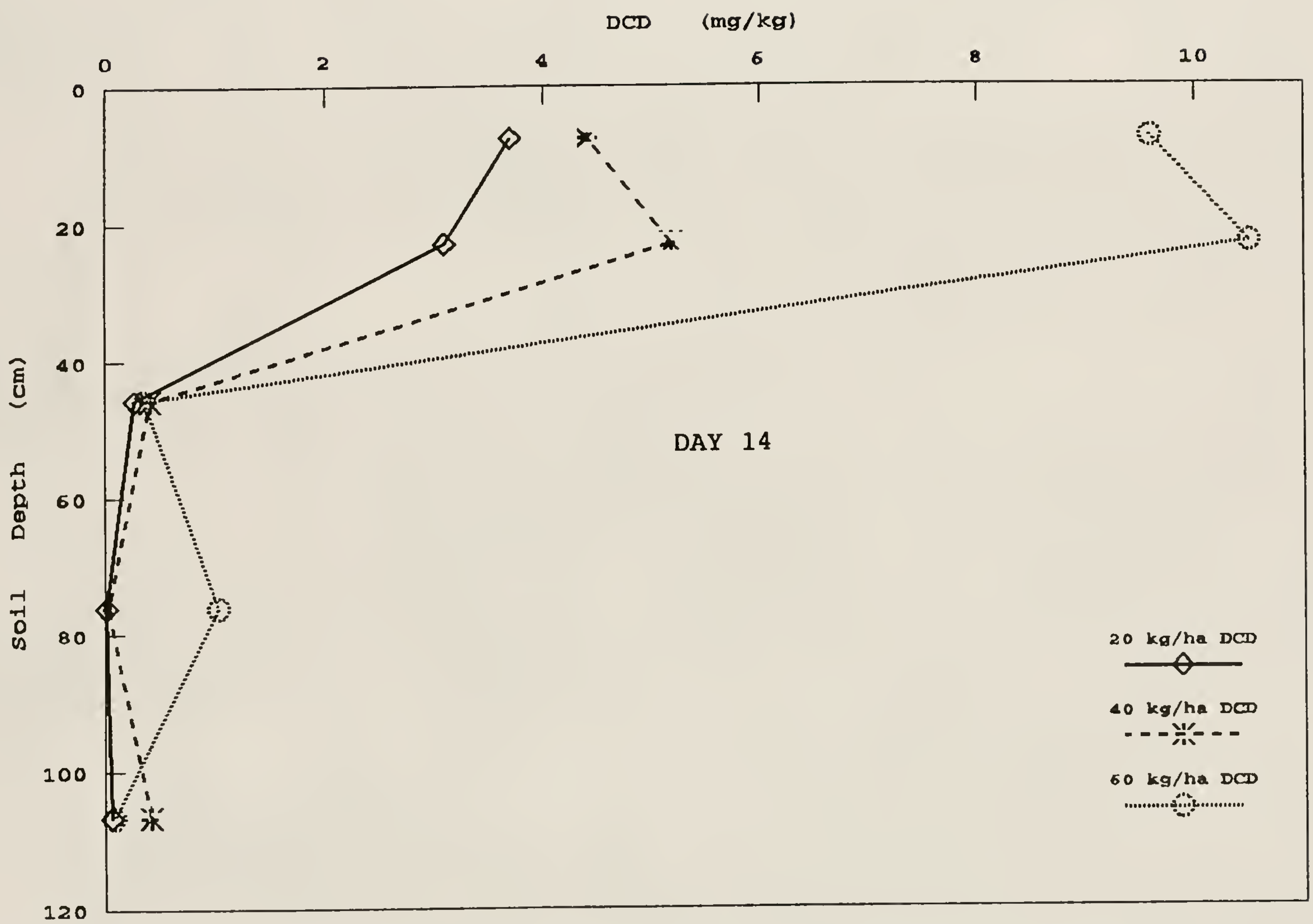

Figure 6-23. Effects of DCD rate on soil DCD concentration with depth 14 days after DCD application to a fallow Quartzipsamment at Live Oak.

Table 6-5. Effects of DCD rate on DCD at five depths over six sampling dates in a Typic Quartzipsamment at Live Oak.

	Days After DCD Application					
Depth (cm)	14	31	46	60	81	116
0-15	L** Qx	L*	NS	L**	Q*	NS
15-30	Lx	L*** Q***	Lx	NS	L*	NS
30-61	NS	NS	NS	Lx	Lx	NS
61-91	Lx	NS	L*	NS	L*	L*
91-122	Q**	NS	NS	NS	L*** Q*	L* Qx
Profile	L*	L** Q*	Lx	L*	L*	Lx

Nonsignificant (NS) or significant at the 0.1 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

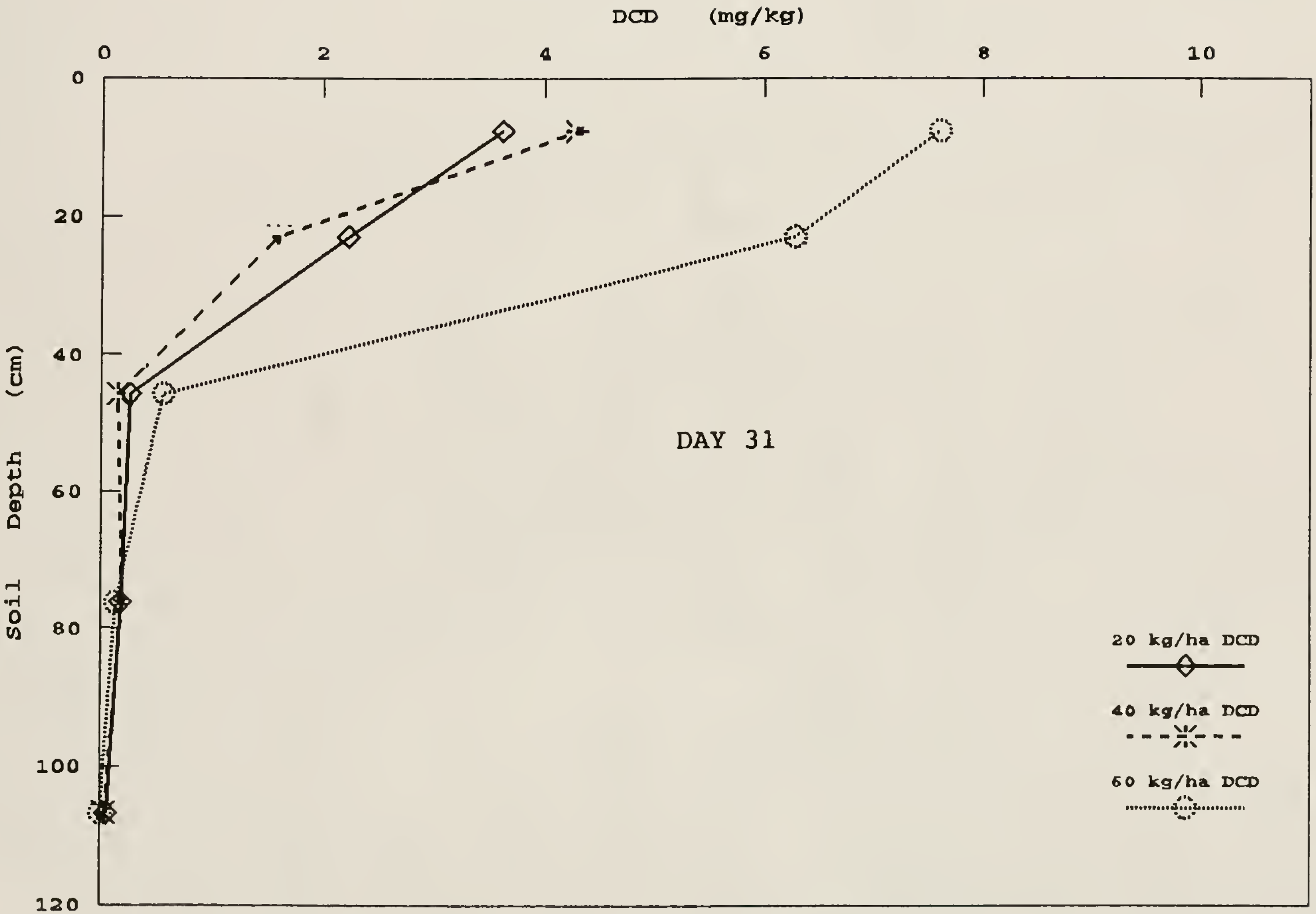

Figure 6-24. Effects of DCD rate on soil DCD concentration with depth 31 days after DCD application to a fallow Quartzipsamment at Live Oak.

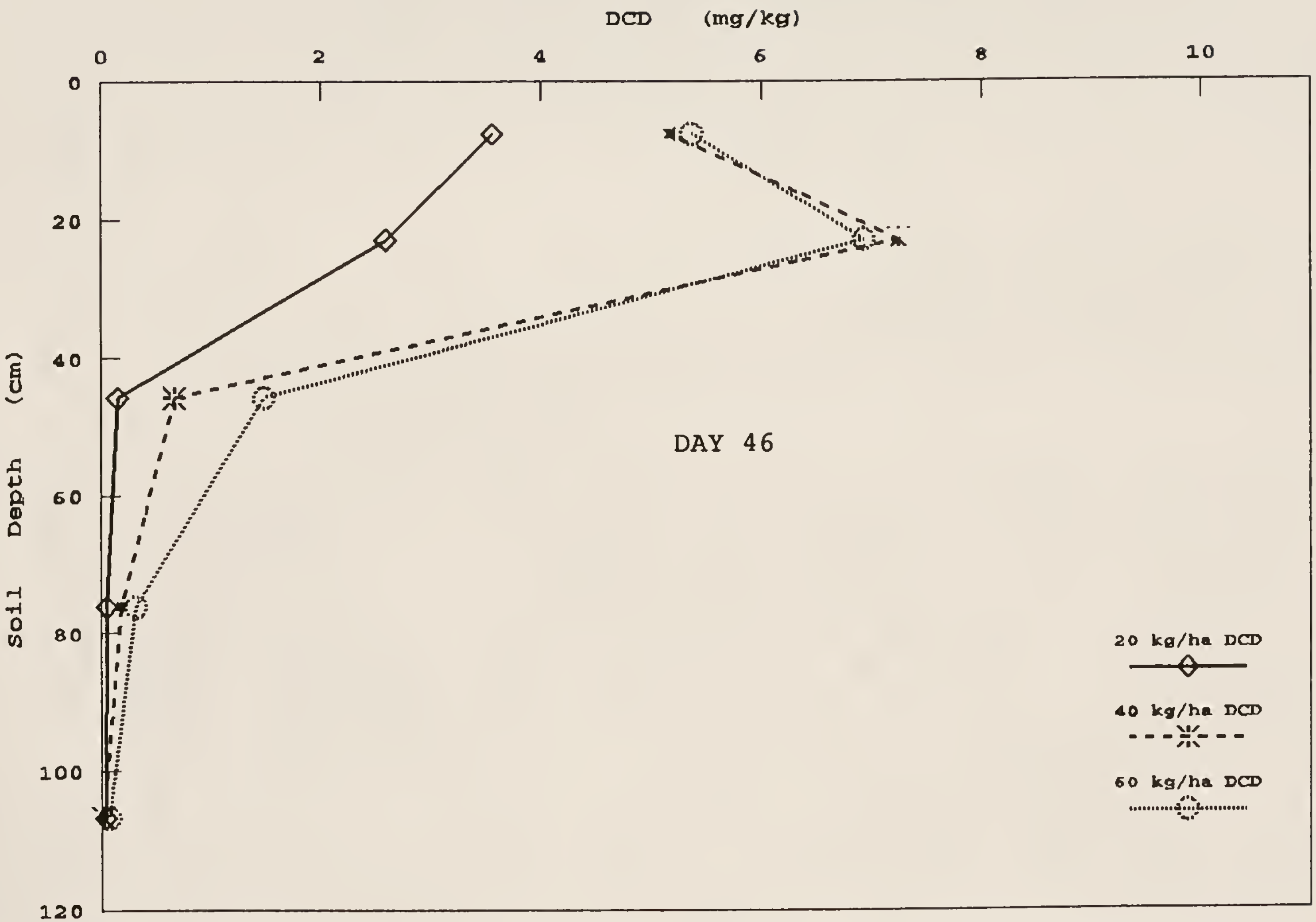

Figure 6-25. Effects of DCD rate on soil DCD concentration with depth 46 days after DCD application to a fallow Quartzipsamment at Live Oak.

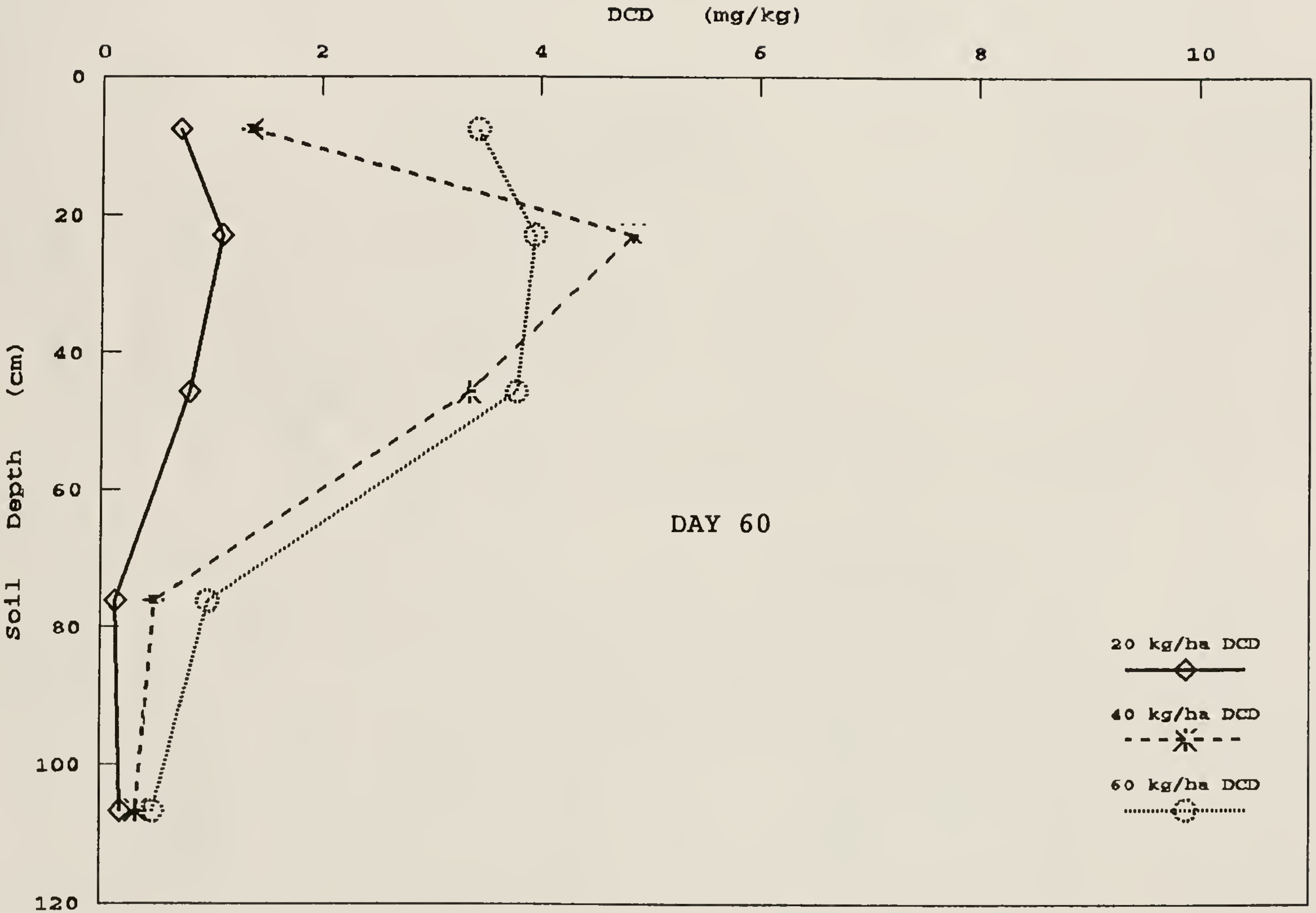

Figure 6-26. Effects of DCD rate on soil DCD concentration with depth 60 days after DCD application to a fallow Quartzipsamment at Live Oak.

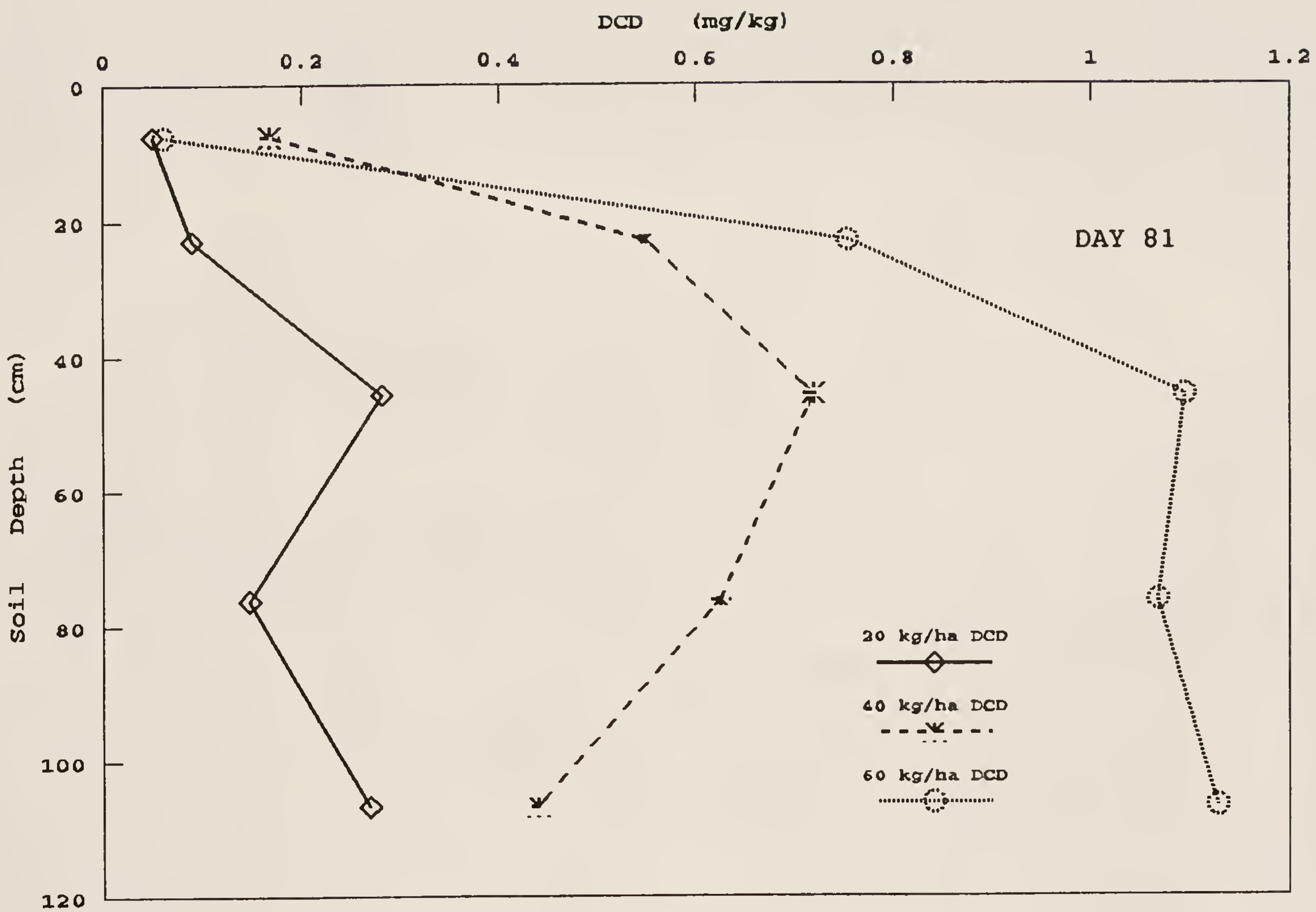

Figure 6-27. Effects of DCD rate on soil DCD concentration with depth 81 days after DCD application to a fallow Quartzipsamment at Live Oak.

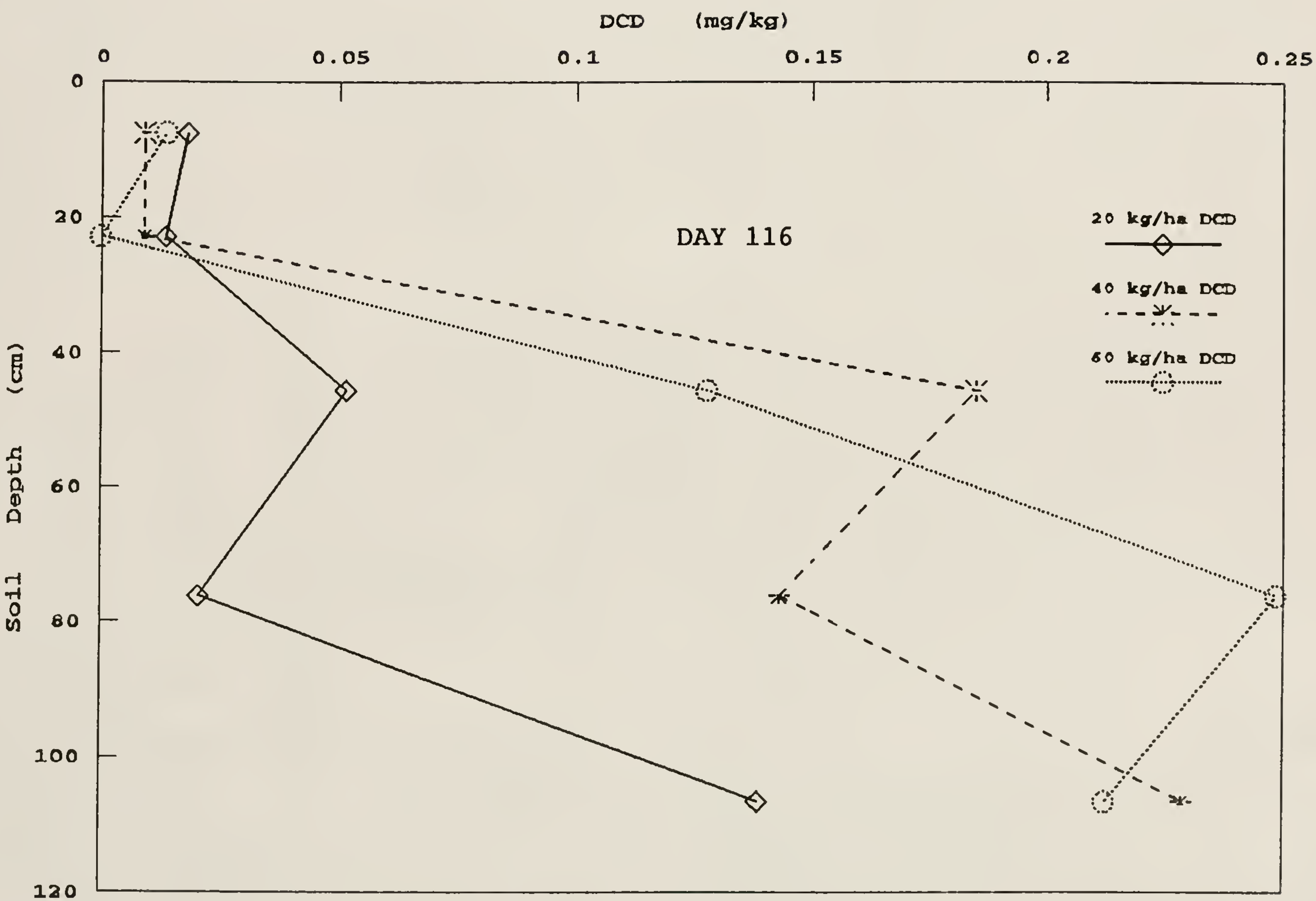

Figure 6-28. Effects of DCD rate on soil DCD concentration with depth 116 days after DCD application to a fallow Quartzipsamment at Live Oak.

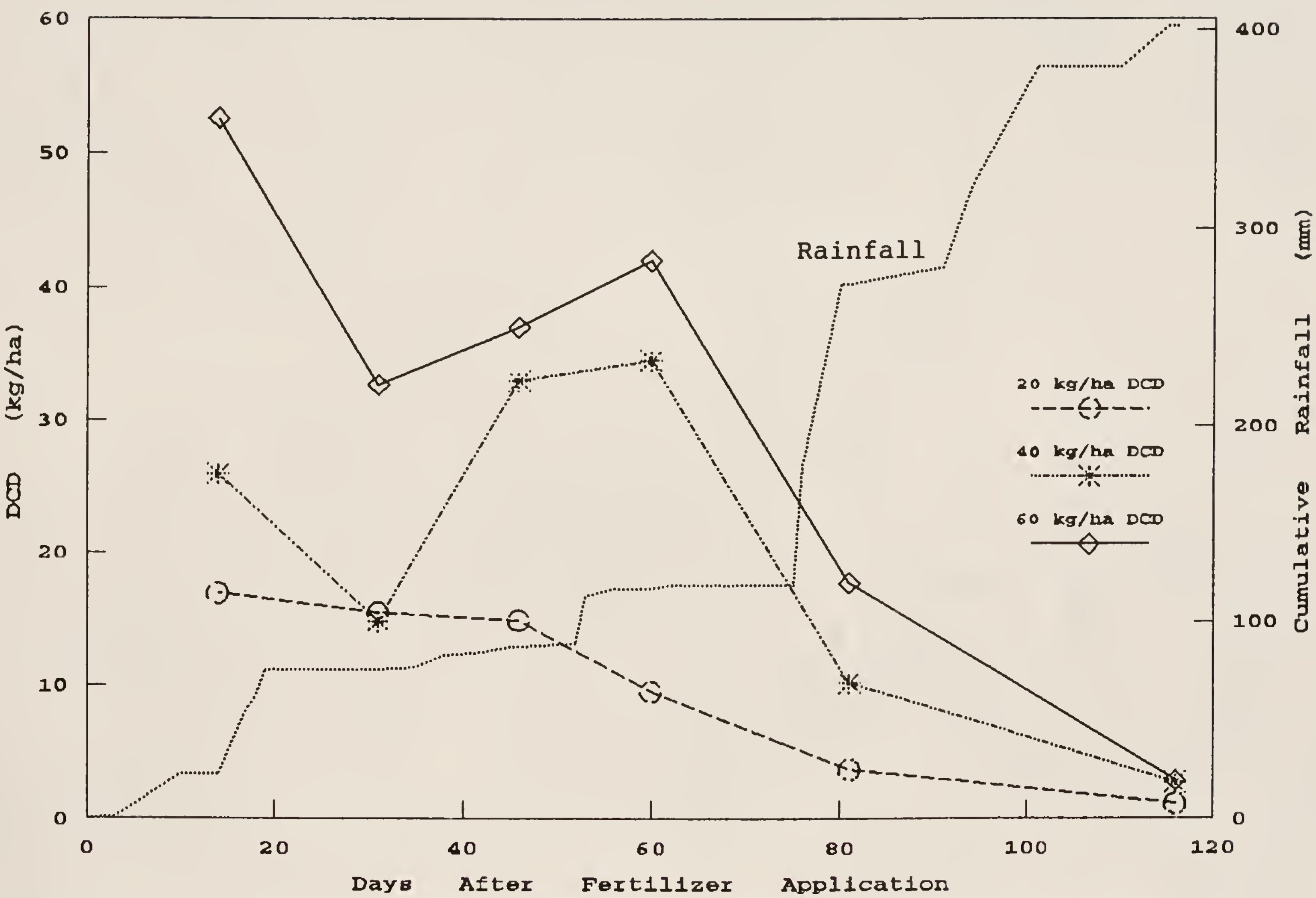

Figure 6-29. Effects of DCD rate on total DCD in the 1.22 m profile of a fallow Quartzipsamment at Live Oak.

estimates. This is particularly true in the case of the 40 and 60 kg ha^{-1} DCD rates. The residence half times thus obtained were 61 (r^2 = -0.9697), 66 (r^2 = -0.7487), and 63 (r^2 = -0.9524) days for the 20, 40, and 60 kg ha^{-1} DCD rates, respectively.

CHAPTER 7
DISCUSSION

Plant Yield/N Content and Soil N and DCD

Tuber Yields

Marketable tuber yields ranged from 26 to 30 t ha^{-1} in 1983, and from 24 to 30 t ha^{-1} in 1984, at Gainesville. At Hastings, marketable yields ranged from 18 to 22 t ha^{-1} in 1983, 16 to 24 t ha^{-1} in 1984, and 29 to 35 t ha^{-1} in 1985. Average potato yields for commercial production in the Gainesville area were 19 and 24 t ha^{-1} for 1983 and 1984, respectively. Average yields in the Hastings area (the primary spring crop potato producing area of Florida) were 26, 31, and 30 t ha^{-1} in 1983, 1984, and 1985, respectively (Florida Crop & Livestock Reporting Service, 1986). Thus, yields obtained in this study were above state averages in 1983 and 1984 at Gainesville and in 1985 at Hastings while being below state averages in 1983 and 1984 at Hastings. In 1983 and 1984 the low yields observed at Hastings were likely due to a combination of rainfall distribution and severe leaching of fertilizer salts by the subsurface irrigation systems.

Tuber Quality

Since these tubers were largely intended for processing into potato chips, high specific gravity values were very desirable. Tuber specific gravity values in this study ranged from 1.0723 to 1.0910. Generally tuber specific gravity values between 1.061 and 1.090 are considered normal for most types of potatoes (Curwen et al., 1982).

Tuber specific gravity was increased by N rate in two out of five year-location combinations and was decreased by DCD in one of the five year-location combinations. Nitrapyrin effects were mixed, but resulted in higher tuber specific gravity values than did DCD in three out of five year-location combinations. In all cases tuber specific gravities with the IBDU treatment were similar to those with the inhibitor treatments.

The proportion of marketable yield that was grade A ($\geq$ 4.8 cm tuber diameter) is an important measure of crop quality, particularly in areas such as Northeast Florida where most of the potato crop is processed into potato chips. Grade B tubers are too small to be processed into potato chips, thus they are usually sold at a lower price. A direct relationship was observed between proportions of marketable yield that were grade A, and tuber yields.

The proportion of total yield that was marketable, as reported by Sanderson and White (1987), reflects the proportion of marketable v cull tubers. Cull tubers are either

rotten, misshapen, or damaged by the harvester or grader, and are of no economic value in most situations. If a treatment increases the proportion of total yield that is marketable, then the value of the crop is increased. An inverse relationship was observed between proportions of total yield that were marketable and tuber yields. Reasons for this were not apparent.

Treatment Effects

Nitrogen rate effects. When 67, 134, and 202 kg ha^{-1} N were applied, soil NH_4^+-N, NO_3^--N, and SIN concentrations increased with increases in N rate on all sampling dates, including at harvest. In 1983 when only 134 and 202 kg ha^{-1} N were applied, N rate effects on NH_4^+-N, NO_3^--N and SIN were limited to the first 60 days after fertilizer application. In 1984 and 1985, a lower N rate (67 kg ha^{-1}) was included with the 134 and 202 kg ha^{-1} N rates. Thus the probability of obtaining N responses was greater than in 1983. A positive tuber yield response to an increase in N rate from 67 to 134 kg ha^{-1} did occur in 1984 at both locations and in 1985 at Hastings. In all cases this yield increase was approximately 4 t ha^{-1}. Only in 1983 at Hastings, was tuber yield increased (3 t ha^{-1}) by an increase in N rate from 134 to 202 kg ha^{-1}. These N rate effects on potato were similar to those obtained by other workers (Giroux, 1982; Kleinkopf et al., 1981; Meisinger, 1976; Murphy and Goven, 1975; Painter and Augustin, 1976). In no case was a "no N"

control included in any of the trials because on most Florida soils, essentially no yield would be obtained. Positive N rate effects on soil inorganic N concentrations led to increases in many potato plant parameters such as yield (Table 7-1).

Interactions between inhibitor and N rate effects. In several cases inhibitor effects were more pronounced or only present at lower N rates. This was the case in several instances in 1984 at Hastings. The reasons for this type of interaction were somewhat different with the soil inorganic NH_4^+-N and NO_3^--N data than with the plant yield and plant N data, though a cause and effect relationship sometimes appeared to be present. In some cases inhibitors had greater inhibiting effects on nitrification at low N rates. This was likely a result of a greater ratio between inhibitor and NH_4^+ concentrations with the low N rates i.e., more inhibitor per unit of NH_4^+.

An explanation was needed for why nitrification inhibition often had more favorable effects on total soil inorganic N concentrations at low than at high N rates. At low N rates, when inhibitors were effective, though soil NO_3^--N concentrations were reduced for a time, soil NH_4^+-N concentrations were sometimes increased. If increases in soil NH_4^+-N concentration exceeded decreases in soil NO_3^--N concentrations, the result was an increase in total soil

Table 7-1. Summary of positive N rate effects on potato plant parameters.

Number of Tests	Plant Parameters
4/5	Marketable and total yield.
4/5	Proportion of marketable yield that was Grade A.
1/5	Proportion of total yield that was marketable.
2/5	Specific gravity.
4/4	Tuber N concentration.
3/4	Plant shoot biomass.
3/4	Total biomass.
3/4	Plant shoot N concentration at harvest.
3/4	N uptake by plant shoots.
4/4	Total N uptake by plant shoots and tubers.
3/5	Leaf N concentration at tuber initiation.
4/4	Leaf N concentration at flowering.
4/4	Leaf N concentration at tuber maturation.

inorganic N. This was the case in 1983 at Hastings with the 134 kg ha^{-1} N rate. Similar effects were observed by Touchton (1981b) when DCD and urea were applied to winter wheat. At higher N rates however, reductions in soil NO_3^--N concentrations often equaled increases in soil NH_4^+-N concentrations. Thus, SIN concentrations did not increase. Graetz et al. (1981) observed a similar effect 67 days after DCD and nitrapyrin were applied with 224 kg ha^{-1} N as NH_4NO_3 to a mulched soil planted to tomato at the Horticulture Unit near Gainesville. Randal and Malzer (1981) also observed this type of DCD effect when 168 kg ha^{-1} N was applied to corn in Minnesota. In several instances, reductions in soil NO_3^--N concentrations exceeded increases in soil NH_4^+-N concentrations. Thus SIN concentrations were reduced by the inhibitors. This occurred in 1984 at Hastings. Similar results were observed by Touchton (1981a) 4 weeks after application of nitrapyrin and urea to grain sorghum. This may have been because much of any increase in soil NH_4^+-N was consumed by soil heterotrophic microorganisms (Norman et al., 1989; Walters and Malzer, 1990a, 1990b), lost due to leaching, (Walters and Malzer, 1990b), or lost due to NH_3 volatilization (Rodgers, 1983).

It may be that for a given soil and climate, there is a maximum limit to the soil inorganic NH_4^+-N concentration that can be maintained. Such maximum limits exist for soil organic N and organic C concentrations (Alexander, 1977).

Such a maximum limit in soil NH_4^+-N concentration is less likely to be reached with a low N rate such as 67 kg ha^{-1} than with a higher N rate such as 202 kg ha^{-1}.

Walters and Malzer (1990b) found that with 90 and 180 kg ha^{-1} N, immobilization of fertilizer N was increased when 0.56 kg ha^{-1} nitrapyrin was applied. They observed that a greater proportion of applied N was leached with 180 than with 90 kg ha^{-1} N. Thus, a greater proportion of applied N was immobilized with 90 than with 180 kg ha^{-1} N. This relationship was accentuated when nitrapyrin was applied. With 80 kg ha^{-1} N, however, plant uptake of N did not decrease with nitrapyrin. This was because in the first year, fertilizer N lost to plant uptake as a result of nitrapyrin induced immobilization was compensated for by nitrapyrin induced mineralization of soil organic N. In succeeding years, this immobilized fertilizer N was mineralized and taken up by the plants. With 180 kg ha^{-1} N, however, stimulation by nitrapyrin of immobilization was apparently exceeded by stimulation by nitrapyrin of mineralization. As a result, in some cases nitrapyrin resulted in an increase in N leaching loss with the 180 kg ha^{-1} N rate.

In some cases inhibitors or IBDU did increase SIN concentration at all N rates but plant yield or plant N content increased only with the low N rate. This type of interaction was likely due to N supply to the plant being

limiting with the low N rate but not with the high N rate, with or without inhibitors. If N supply to the plant is not growth limiting at a high N rate, then amendments that increase SIN concentration over time, will not increase plant growth or yield (Blackmer, 1986). This assumes that inhibition of nitrification will conserve soil N and increase the supply of SIN available to the plant. As was shown in Chapters 5 and 6 and by Norman et al. (1989) and Walters and Malzer (1990a, 1990b), this assumption is often invalid in the field.

In some cases, since inhibition of nitrification only increased soil inorganic N with the low N rate, plant yield or plant N content parameters were only increased with the low N rate. In such a case, a direct cause and effect relationship would be indicated, with the effects of nitrification inhibition on soil inorganic N concentrations being reflected by similar effects on the means of plant parameters.

Interactions were not consistent, often following no logical pattern. In several cases inhibitor effects were greater or only significant at a medium or high N rate. No explanation for this was apparent. The data in Table 5-7 are an example of this. These kinds of patterns may have been due to some soil microbiological or plant physiological relationships that was not understood but more likely they were a result of high variability in the data.

More interactions were observed with leaf N at flowering than with any other plant parameter. The reason for this was likely a high sensitivity on the part of leaf N status at flowering to SIN concentrations. Leaf N at flowering (66 to 81 dap) is reflective of a time during which the tuber bulking stage is well under way and leaves must compete with tubers for N taken up by the roots (Kleinkopf et al., 1981). Several workers have suggested that the ideal stage of potato plant growth for leaf tissue sampling is at the 10% bloom stage (McKay et al., 1966).

The early (43 to 55 dap) leaf N samplings provide information on the N status of the plant during the latter portion of the vegetative growth stage or the tuberization stage, prior to the tuber growth (bulking or enlargement) stage (Kleinkopf et al., 1981). During the vegetative stage there is no competition for soil N uptake between the plant shoots and tubers. Gardner and Jones (1975) were of the opinion that leaf samples should be taken on at least two separate dates (early- and mid-season) to reliably determine the nutrient status of a given field of potato. In Florida's subtropical climate, maximum total dry matter accumulation occurs between 52 and 69 days after planting (corresponding to the time between the early- and at-flowering sampling dates in this study), followed by a rapid decline with the onset of hot weather; this is about 30 days earlier than that reported in northern trials (O'Hair, 1985). By

the time of the late leaf sampling (93 to 98 dap) the plants were past the tuber bulking stage and in the latter part of the tuber maturation stage. During this last stage, N and carbohydrates move from the shoots and roots into the tubers (Kleinkopf et al., 1981).

Dicyandiamide rate effects. Dicyandiamide did not inhibit nitrification in 1983 at Gainesville, since it did not decrease soil NO_3^--N concentrations or the NO_3^--N/(NO_3^--N + NH_4^+-N) ratio (see Appendix C for data and Appendix D for analysis of variance). Dicyandiamide at rates of 5.6 and 11.2 kg ha^{-1} did not increase soil NH_4^+-N or SIN concentrations. The only positive DCD rate effect on potato plant parameters in 1983 at Gainesville, was leaf N concentration at flowering. Potato leaf N concentration at flowering is quite sensitive to soil inorganic N status. The NO_3^--N/(NH_4^+-N + NO_3^--N) ratio was increased with DCD on day 59 at the 134 kg ha^{-1} N rate, indicating a greater proportion of soil N in the NO_3^- form available to the plant ten days before these leaf samples were taken.

In 1984 at Gainesville, increasing DCD rate resulted in an increase in soil NH_4^+-N concentration on only one of five sampling dates (see appendices C and D). All soil NO_3^--N concentrations were very low in 1984 at Gainesville. This was likely due to this soil receiving 506 mm of rain during the growing season, as well as supplemental overhead irrigation. Soil NO_3^--N concentrations were generally

decreased by DCD with 67 kg ha^{-1} N but increased with 202 kg ha^{-1} N. The NO_3^--N/(NO_3^--N + NH_4^+-N) ratio was decreased on all but day 13 with the 67 kg ha^{-1} N rate. Thus, inhibition of nitrification was limited to the lowest N rate. The total soil inorganic N concentration was increased by DCD only on day 69.

Leaf N concentration at tuber initiation was decreased by DCD in 1984 at Gainesville. The soil inorganic N data do not indicate why this should have been the case. Leaf N concentration at flowering was increased by DCD. This may have been related to DCD induced increases in soil NH_4^+-N and total soil inorganic N on day 69. No relationship was apparent between soil inorganic N concentrations and the quadratic DCD rate effect on late leaf N concentration. With increases in DCD rate, tuber N concentration decreased with the low N rate and increased with the medium and high N rates. This may have been due to effects of the soil NO_3^--N/(NO_3^--N + NH_4^+-N) ratio on tuber N. This ratio was decreased by DCD with the low N rate while it was increased with increases in N rate. Potato has a preference for NO_3^--N (Volk and Gammon, 1954; Pollizotto et al., 1975) thus increases in the soil NO_3^--N/(NO_3^--N + NH_4^+-N) ratio may tend to increase tuber N concentration. Touchton (1981b) observed a similar decrease in wheat grain N concentration with DCD applied at a low N rate (34 kg ha^{-1}).

Severe leaching and/or denitrification occurred in 1983 at Hastings, possibly induced by the failure of the sub-irrigation system to keep the water table far enough below the fertilizer band (B.L. McNeal, personal communication, see further discussion below). This led to potato yields that were quite low. Soil inorganic N concentrations decreased followed by an increase. Soil NH_4^+-N concentration was increased substantially by DCD but there were no effects on soil NO_3^--N. Graetz et al (1981) also observed an increase in soil NH_4^+-N concentration without a decrease in soil NO_3^--N concentration on one of the sampling dates in one of their nitrification inhibitor studies.

Because of favorable effects of DCD on soil inorganic N in 1983 at Hastings, DCD had positive effects on several potato plant parameters. Tuber yield was increased by DCD with the low N rate. In a similar study nitrification inhibitor increased SIN concentration at both of two N rates but increased corn grain yield only at the low N rate (Touchton et al., 1979).

In 1984 at Hastings, soil NH_4^+-N concentrations were initially decreased by DCD up to day 18 (particularly at the 202 kg ha^{-1} N rate), and subsequently increased by DCD (see Appendices C and D). Decreases in soil NO_3^--N concentrations on most sampling dates were caused by DCD, particularly with the 67 kg ha^{-1} N rate. The NO_3^--N/(NH_4^+-N + NO_3^--N) ratio was decreased by DCD throughout the latter two

thirds of the season thus DCD quite effectively inhibited nitrification. The SIN concentration was, however, not increased by DCD at any time. It decreased on two sampling dates, particularly with the 202 kg ha^{-1} N rate because decreases in NO_3^--N concentrations exceeded increases in NH_4^+-N concentrations.

Because there were no favorable DCD effects on SIN concentrations in 1984 at Hastings, there were only a few mixed DCD effects on potato plant parameters in 1984 at Hastings. Early leaf N concentration was increased, probably due to the increase in soil NH_4^+-N concentration on day 32, but leaf N concentration at flowering was reduced by DCD.

No soil inorganic N data was collected in 1985 at Hastings, but the only DCD effects on potato plants were a decrease in specific gravity and a slight increase in leaf N concentration at flowering.

Among all five year-location combinations the effects of DCD led to an increase in several plant parameters, though in some cases only at certain N rates. These parameters included tuber yield, the proportion of marketable yield that was grade A, tuber N concentration, total biomass, and total N uptake.

Application of DCD led to decreases in specific gravity and plant shoot N concentration at one year-location combination each. Leaf N concentration at flowering

increased with increased DCD rate in three out of four year-location combinations. In the fourth year-location combination, DCD resulted in decreased leaf N concentration at flowering.

A similar study was conducted in 1983 and 1984 at the Horticulture Unit near Gainesville on a Typic Ochraquult (Mohamad, 1985) less than 100 m from where potato was grown in this study. Mohamad (1985) applied 67, 134, and 202 kg ha^{-1} N with 0, 11.2, or 22.4 kg ha^{-1} DCD to sweet corn. Soil was sampled only from plots receiving 202 kg N ha^{-1}. In 1983, 22.4 kg ha^{-1} DCD resulted in increased soil NH_4^+-N concentrations for up to 56 days while 11.2 kg ha^{-1} DCD increased soil NH_4^+-N concentration for 28 days after urea fertilizer application. Soil NO_3^--N concentration was decreased with DCD for 28 days (Mohamad, 1985). In our study in 1983 at Gainesville, DCD had very little effect on soil inorganic N concentrations.

In 1984, Mohamad (1985) found that soil NH_4^+-N concentration was increased only at the 42 day sampling with 22.4 kg ha^{-1} DCD but was little affected with 11.2 kg ha^{-1} DCD. In that same year, 22.4 kg ha^{-1} DCD resulted in decreased soil NO_3^--N concentration only on day 28. With 11.2 kg ha^{-1} DCD, soil NO_3^--N concentration was not affected (Mohamad, 1985). In our study in 1984 at Gainesville, soil NO_3^--N and NO_3^--N/(NH_4^+-N + NO_3^--N) ratio data indicated that

11.2 kg ha^{-1} DCD did not inhibit nitrification with 202 kg ha^{-1} N although SIN concentration increased on one of five sampling dates.

In 1983 Mohamad (1985) observed no DCD effect on total marketable sweet corn yield. In 1984 sweet corn yield increased with an increase in DCD rate from 0 to 11.2 kg ha^{-1} but decreased with a further increase in DCD rate to 22.4 kg ha^{-1}. Dicyandiamide had no effect on plant biomass in either year. In 1983 DCD decreased sweet corn shoot N concentration at harvest with 134 kg ha^{-1} N.

Nitrapyrin rate effects. In 1983 at Gainesville, nitrapyrin rate had no effect on potato plant parameters because there were no nitrapyrin rate effects on any soil inorganic N parameters. In 1984, however, effects of increasing nitrapyrin rate on soil N parameters tended to be favorable with the low N rate and unfavorable with the high N rate at Gainesville. Thus, it was reasonable that tuber N uptake increased with an increase in nitrapyrin rate with the low N rate but was not affected with the high N rate. Plant shoot N uptake decreased with an increase in nitrapyrin rate with the high N rate but was not affected with the low N rate. No logical explanation was apparent why one plant parameter should have been affected with the low N rate and the other with the high N rate, other than natural biological variation or experimental variation in the data.

No effects of nitrapyrin rate were observed on soil inorganic N concentration in 1983 at Hastings. However, soil samples were not taken beyond day 61 because the potato plants were of such an unthrifty appearance, it was thought that no additional useful information would have been gained thereby. There may have been nitrapyrin rate effects on inorganic soil N that were missed. This was likely because an increase in nitrapyrin rate increased tuber yield (134 kg ha^{-1} N rate only), the proportion of marketable tubers that were grade A, tuber N concentration (particularly with 202 kg ha^{-1} N), total biomass (particularly with 134 kg ha^{-1} N), plant shoot N concentration (134 kg ha^{-1} N only), and total N uptake.

In 1984 at Hastings, an increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1} resulted in decreased NO_3^--N/ (NH_4^+-N + NO_3^--N) ratios on days 32 and 46. Thus, nitrification was reduced mid-way through the season by nitrapyrin. Increasing nitrapyrin rate resulted in increased NO_3^--N and SIN concentrations on one sampling date and increased NH_4^+-N concentration on another. These favorable effects on soil inorganic N concentration were reflected by an increase in tuber specific gravity and increases in leaf N concentration at flowering at two of three N rates. With 202 kg ha^{-1} N, however, an increase in nitrapyrin rate resulted in decreased plant shoot biomass in 1984 at Hastings.

Dicyandiamide v nitrapyrin. The results for this contrast were mixed. Nitrapyrin seemed to inhibit nitrification somewhat more effectively than DCD in 1983 at Gainesville. No differences were observed, however, between the inhibitors in their effects on SIN concentrations. Thus, no differences were observed between the two inhibitors in their effects on any potato plant parameters.

In 1984 at Gainesville, the two inhibitors seemed about equally as effective at inhibiting nitrification in this soil. Though SIN concentrations were higher with nitrapyrin early and late in the season, these were not times of critical N supply for the potato plant. Apparently higher concentrations of soil NO_3^--N with DCD during the tuber enlargement stage were sufficient to result in higher values for tuber yield and several other potato plant parameters with DCD than with nitrapyrin. This may have been due to the preference by potato for NO_3^--N over NH_4^+-N. The only plant parameter for which values were greater with nitrapyrin was tuber specific gravity.

In a similar study NH_4NO_3, DCD and nitrapyrin were applied to tomato at Gainesville (Graetz et al., 1981). Their data indicated that at all soil sampling dates, while DCD resulted in higher soil NH_4^+-N and SIN concentrations, nitrapyrin resulted in higher soil NO_3^--N concentrations. As a result, tomato yields were slightly higher with nitrapyrin.

No differences were observed between the two inhibitors in their effects on any soil inorganic N parameters in 1983 at Hastings. The only difference between the inhibitors in their effects on potato plant parameters, was a greater N uptake by tubers with the DCD treatments, and this only with the 134 kg ha^{-1} N rate.

In 1984 at Hastings, comparison between the two inhibitors gave mixed results. Soil NO_3^--N and NO_3^--N/(NH_4^+-N + NO_3^--N) ratio data indicated that nitrification was inhibited somewhat more effectively by DCD than nitrapyrin. Nitrapyrin, however, resulted in higher soil NH_4^+-N, NO_3^--N, and SIN concentrations. It is reasonable therefore, that nitrapyrin resulted in higher concentrations of leaf N at flowering. Nitrapyrin also resulted in higher tuber specific gravity values than did DCD. With other plant parameters, however, there appeared to be an inverse relationship between soil N effects and plant effects. Dicyandiamide resulted in higher values for several potato plant parameters including tuber yield. Two of these differences were present only with the 202 kg ha^{-1} N rate. Soil N levels were apparently not a good predictor of yield in this test. Yields were below state average in spite of apparently adequate soil inorganic N levels. This was the only test where values for a plant parameter (plant shoot biomass at harvest) decreased with increases in N rate. Possible

explanations for this may have included high soil salinity or hail damage.

In 1985 at Hastings, the DCD treatments resulted in higher values for yield and leaf N concentration at tuber initiation (with the medium N rate only) while tuber specific gravity values were higher with the nitrapyrin treatments.

Considering all year-location combinations, the potato yield, biomass, and plant N concentration data were in most cases reflective of the trends in the soil N data for this comparison. Tuber yields were higher with DCD in three of five tests. Tuber specific gravity values, however, were higher with nitrapyrin in three of five tests. No explanation can be offered as to why tuber specific gravity values were higher with nitrapyrin than with DCD.

Inhibitors v IBDU. In many cases, the IBDU treatment resulted in higher soil inorganic N concentrations than did the inhibitor treatments. Higher soil N values with IBDU in 1983 at Gainesville, were responsible for higher tuber and shoot N uptake and concentration and higher leaf N concentration at flowering. There was no difference, however, between IBDU and the inhibitors in their effects on tuber yield, tuber quality, or biomass in 1983 at Gainesville.

Overwhelmingly favorable effects by IBDU on soil inorganic N concentrations did little to improve potato plant growth in 1984 at Gainesville. The only plant

parameter, the means of which were higher with IBDU than with inhibitors, was leaf N concentration at tuber initiation. The reasons for this discrepancy in 1984 at Gainesville, were not apparent.

In 1983 at Hastings, the IBDU v inhibitors contrast was contradictory. Soil NO_3^--N concentrations were higher with IBDU on one date while the percent of total yield that was marketable at the high N rate and leaf N concentration at flowering were higher with inhibitors.

In 1984 at Hastings, in the first 18 days of the growing season, soil NH_4^+-N, NO_3^--N, and SIN concentrations were generally higher with inhibitors. By day 32 or 46, the trend was reversed with IBDU resulting in higher soil inorganic N values. This pattern was most likely due to the slow release character of IBDU, which was added as one-third of total applied N. In several cases, the advantage with IBDU increased with increasing N rate. Potato plant parameters showed mixed IBDU v inhibitors contrasts and interactions with N rate effects as a result of these soil inorganic N differences. Leaf N at flowering was higher with IBDU and tuber yields with 67 kg ha^{-1} N were higher with IBDU because soil inorganic N values were higher with IBDU after tuber initiation. In 1985 at Hastings, leaf N at flowering was higher with inhibitors but the percent of total yield that was marketable was higher with IBDU.

In 1983 and 1984 at both locations, IBDU was more effective than the nitrification inhibitors, for maintaining plant available N in the rooting zone during the middle and latter portions of the growing season. This difference was reflected in only a few cases, however, by greater tuber yield, plant N concentration and N uptake with IBDU.

Irrigation and Rainfall Effects

Most of the NH_4^+-N and NO_3^--N leached out or was otherwise lost from the soil in 1983 at Hastings, less than five days after fertilizer application. The SIN concentration was less than 10 mg kg^{-1} on the fifth day after fertilizer application. The rainfall data does not indicate that rainfall caused this N loss. Figure 5-3 does not show any substantial amount of rain falling during this time period. The total recorded rainfall during the growing season was 329 mm, not an excessive amount. The possibility of intense leaching rainfall cannot be entirely ruled out in this case, however. Immediately after planting and fertilizer application in 1983 at Hastings, an intense rain occurred at the field site which was not recorded by the rain gauge positioned a few hundred meters away and thus, was not reflected in the rainfall data. Thus, it is possible that much of the N fertilizer was very rapidly leached below the rooting zone, with little remaining for subsequent upward movement.

It is possible that an excess of water from the subirrigation system rose up into the fertilizer band,

dissolving the fertilizer N. Then the water level dropped, leaching the N downward, and draining it away. This hypothesis was supported by the fact that the low concentrations of soil NH_4^+-N and NO^{3-}-N increased from the second to the third sampling dates, indicating a capillary rise of N dissolved in the sub-irrigation water. The DCD appeared to have largely been leached out as well. As with the soil N, soil DCD concentrations increased with time with the higher of the two DCD rates, lending further credence to the hypothesis just mentioned. Graetz et al. (1981), however, observed similar increases in soil DCD concentrations in a well drained soil with overhead irrigation.

With overhead irrigation, soil NO_3^- and other soluble salts move downward and decrease in concentration as the crop growing season progresses. Elkashif et al. (1983) observed this to be the case at the University of Florida Horticulture Unit near Gainesville. At the Hastings AREC, however, where potato was grown with subsurface irrigation, they observed that in the rooting zone (upper 30 cm) soil soluble salts increased as the season progressed, due to low rainfall and upward movement of soluble salts as water evaporated during dry periods.

These explanations are not sufficient to explain the suddenness and magnitude of the soil inorganic N loss in 1983 at Hastings. Recent unpublished studies of fertilizer N movement in nonmulched, bedded soil with banded fertilizer

over very shallow water tables in South Florida, indicate that a previously undescribed mechanism of fertilizer N loss may be operative in soils planted to potato and other vegetables under these conditions (B. L. McNeal, personal communication). These conditions include fertilizer bands that are approximately 10 cm below the top of the soil bed, and drainage and/or subsurface irrigation systems that are designed to maintain the water table level at about 30 to 40 cm below the top of the soil bed, and just below the soil surface in the furrows between the soil beds.

When the water table rose up into the lower portion of the soil beds, capillary movement of water even in these very sandy soils, was sufficient to lead to water saturated conditions in the soil just below the fertilizer band. The presence of the band of fertilizer salts just above the saturated zone, led to a wick effect, with the salinity gradient pulling water up into the fertilizer band. When this situation was concurrent with heavy rainfall occurring within a day or two of planting and fertilizer application, the fertilizer band became saturated with water. The fertilizer in the fertilizer band had not had sufficient time to become encrusted and the fertilizer salts had not had sufficient time to diffuse out from the band.

An unexpected phenomenon was then observed. A dense layer of highly saline water formed in and around the fertilizer band. The difference in density between this

saline water and the fresh water below it, caused the saline water to flow rapidly (within a few hours) downward below the soil bed and rooting zone. Solute movements that were expected, such as gradual downward diffusion of fertilizer salts, or a slow downward mass flow of dissolved fertilizer salts as water table levels receded downward, were not observed. It was likely therefore that fertilizer N, and possibly fertilizer K and other plant nutrient salts, were lost from the rooting zone in this manner in 1983 at Hastings.

Soil NH_4^+-N and NO^{3-}-N concentrations in 1984 at Hastings, increased from the first to the second sampling. This increase was followed by a substantial decrease in these values beginning approximately 18 days after fertilizer application, concurrent with 83 mm of rainfall within three days and 32 mm of rainfall a few days later. Soil NO^{3-}-N concentration increased from the third to the fourth sampling. As in 1983, this field had a sub-irrigation system, but heavy rainfall did not occur until 19 days after fertilizer application. Thus relatively large (> 30 mg kg^{-1}) amounts of soil NH_4^+-N and NO_3^--N remained for at least 18 days after fertilizer application and "inversion" of dissolved fertilizer salts was delayed and was not as complete as it had been the previous year. This does not adequately explain the very low tuber yields observed in 1984 at Hastings. Possibly the delay in fertilizer salt loss was of

sufficient duration to allow some retention of fertilizer derived soil inorganic N by means of biological immobilization, but not of sufficient duration to allow retention of other essential plant nutrient salts such as K, thus the low yields. No measurements of extractable soil K were conducted, thus it was not possible to test this hypothesis in 1984 at Hastings.

In 1985 at Hastings, soil inorganic N data were not collected. Yields were quite high, probably because intense rainfall (47 mm) did not occur until 26 days after fertilizer application, and because a split application of K fertilizer was made, as recommended (G. Kidder, personal communication). It may also be likely that because only 175 mm of rainfall occurred during the growing season, the water table levels were subject to more control during that year.

Sampling for Soil N When Fertilizer is Banded

In quite a few cases, relatively large absolute differences in soil inorganic N concentrations between treatments were not statistically significant. This was especially true early in the season, particularly with soil NH_4^+-N concentrations. This phenomenon was observed in the studies with potato as well as in the upper 30 cm in the fallow Quartzipsamment. These observations may have been due to nonlinear inhibitor rate effects on soil N immobilization and mineralization.

A more likely reason for this, however, was the high degree of variability commonly encountered with soil inorganic N data. A likely reason for such variability being more extreme early in the season, was the fact that potatoes were grown in bedded soil with all the fertilizer being banded. Soon after planting and fertilizer application (which were simultaneous in all cases), the fertilizer N had not fully diffused from the fertilizer band, causing distribution of inorganic N in the soil bed to be very heterogeneous.

When fertilizer is applied in a band in raised beds or mounds of soil, rather than broadcast on flat ground, collecting a representative sample of soil inorganic NO_3^--N and NH_4^+-N is difficult. Even with the best conventional equipment and tractor operator, normal flexibility of the hitch between the tractor and the planter allows several centimeters of movement, which results in inexact row placement (Sanchez et al., 1987). As a result of this and other factors, fertilizer bands are not always straight horizontally or vertically in relation to the seed pieces, nor are they uniform in thickness of deposition. In addition to the heterogeneity of initial fertilizer concentrations in the soil, downward movement of water and fertilizer salts in potato soil beds is quite irregular (Lesczynski and Tanner, 1976; Saffinga et al., 1976, 1977; Tanner et al., 1982; Simpson and Cunningham, 1982; Rourke, 1985).

The accuracy of soil sampling is also affected by sample volume, with the variance of the observations usually decreasing as the sample size increases (Peck, 1983). Hassan et al. (1983) found that the coefficient of variation for an extracted element that had been uniformly applied to the soil, was greatly reduced by using a wider diameter soil sampling tube, although the mean was the same. Attempts at using a standard 2.2 cm diameter sampling tube for sampling soil into which fertilizer has been banded have resulted in difficulties in obtaining a representative sample, resulting sometimes in suspiciously low measured soil NH_4^+-N and NO_3- concentrations (Fiskell and Robertson, 1957; Graetz et al., 1981). This was why a large diameter sampling tube was used in this study.

When sampling bedded soil planted to potato, the sampling depth should include the entire rooting zone of the plants (Linford and McDole, 1977). This was why soil in these potato field experiments was sampled down to the hardpan, which consistently occurred at about 30 to 33 cm. Considering these obstacles, we were fortunate to observe as many significant treatment effects on soil inorganic N as we did.

<u>Other Observations</u>

While DCD and nitrapyrin sometimes reduced soil NO_3^--N concentrations, increases in soil NH_4^+-N concentrations occurred less frequently. Therefore, the inhibitors

generally did not increase the total inorganic N extracted from the soils except in 1983 at Hastings, in which case salt inversion, leaching and/or denitrification were severe.

Chancy and Kamprath (1982) obtained similar results with nitrapyrin on corn. They observed that nitrapyrin resulted in more of the total inorganic N being in the NH_4^+ form, but this did not significantly increase the total inorganic N concentration. In contrast, Graetz et al. (1981) observed at the Horticulture Unit near Gainesville, that 45 and 61 days after application of urea to soil under mulched tomato, DCD and nitrapyrin treatments resulted in substantial increases in SIN concentrations. In that same experiment, however, SIN concentrations were decreased by inhibitors on some sampling dates. The unusual results obtained by Graetz et al. (1981) may have been due to the effects of plastic mulch on NH_3 volatilization, N leaching and/or N immobilization.

Recent work with ^{15}N labeled fertilizer and DCD applied to paddy rice (Norman et al., 1989) and nitrapyrin applied to corn on field lysimeters (Walters and Malzer, 1990a, 1990b) sheds light on what is now an old enigma. Their work indicates that the reason why nitrification inhibitors often do not increase SIN concentrations is the confounding effects of inhibitors on N immobilization and mineralization. Thus, these effects, not the lack of

leaching rainfall, are the primary reason why nitrification inhibitors usually do not increase crop yields.

With NH_4NO_3 as the fertilizer N source in 1983 and 1984, soils began the season with an equal amount of fertilizer derived NH_4^+-N and NO_3^--N. The data described in these studies show that even in these very sandy soils of low clay and organic carbon content, NO_3^--N was much more rapidly leached or otherwise removed from the soil, than was NH_4^+-N. The only year-location combination where substantial amounts of NO_3^--N persisted in the soil for even 18 days after fertilizer application, was in 1984 at Hastings. This was likely due to low rainfall during the season (294 mm) and use of sub-irrigation.

The inhibitors usually had little or no inhibiting effect on nitrification, or favorable effects on soil NH_4^+-N concentrations with the earliest sampling dates. This may have been due in part to the fact that the fertilizer N was applied as NH_4NO_3. Ammonium nitrate is generally not the best N source to apply when studying the effects of nitrification inhibitors. However, potatoes require a mixed N source for optimum growth (Chen and Li, 1978; Davis, 1983; Davis et al., 1986b; Hendrickson et al., 1978; Loescher, 1981; Meisinger et al., 1978; Middleton et al., 1975; Painter and Augustin, 1976; Pollizotto et al., 1975; Terman et al., 1951; Volk and Gammon, 1954).

Other workers, however, have observed similar results with NH_4-N and urea. Touchton (1981a) added 60 mg kg^{-1} NH_4^+-N to an Alabama soil with nitrapyrin and DCD. Nitrapyrin and one of two DCD rates appeared to have decreased SIN concentration 28 days after application. Ten days after application of urea to a mulched soil at Gainesville, Graetz et al. (1981) found that DCD and nitrapyrin resulted in decreased soil NH_4^+-N, NO_3^--N, and SIN concentrations. Twenty-eight days after application of urea to an unmulched soil at Gainesville, Graetz et al. (1981) found that 10% N as DCD-N decreased soil NH_4^+-N and SIN concentrations substantially. This was attributed to inhibition of urea hydrolysis by DCD.

Though Sommer and Rossig (1978) attributed urease inhibiting activity to DCD, they showed no evidence for this. Amberger and Vilsmeier (1979c) demonstrated that DCD does not inhibit urease. Nitrapyrin has also been shown to have no effect on urease activity (Goring, 1962a; Bundy and Bremner, 1974; Westerman et al., 1981). Initial nitrification inhibitor inactivity and initial reductions in soil inorganic N concentrations due to DCD and nitrapyrin, are more likely caused by a combination of several other factors. These include inhibitor effects on fertilizer N immobilization (Smirnov et al., 1968; 1972a; 1972b; 1973; 1976a; 1976b; 1977; Ashworth, 1986; Norman et al., 1989; Walters and Malzer, 1990b) and NH_3 volatilization (Rodgers, 1983). In addition, such inhibitor effects may be

confounded by the initial priming effect of fertilizer N on organic N mineralization (Walters and Malzer, 1990b).

Soil DCD.

It was approximated that the time required for half of the DCD applied to disappear from the potato rooting zone ranged from 30 to 70 days. Residual DCD concentrations on the last sampling dates 98 to 108 days after fertilizer application ranged from 0.1 to 0.6 mg kg^{-1} for the three location year-combinations where late samples were taken. The higher residual values occurred at Hastings, where rainfall amounts were low and subsurface irrigation was used, resulting in incomplete leaching and upward as well as downward movement of DCD and other solutes in the soil beds. Comparison of these data with those of Mohamad (1985) indicate that at Gainesville with 202 kg ha^{-1} N, 11.2 kg ha^{-1} DCD is sometimes not sufficient for effective inhibition of nitrification. No conclusion can be drawn, however, regarding the minimum concentrations of soil DCD necessary for inhibition at Hastings, or at either location when 67 or 134 kg ha^{-1} N are applied.

Urea and DCD Applied to a Fallow Quartzipsamment

Soil Inorganic N

Though DCD would be expected to increase soil NH_4^+-N concentrations (Goring, 1962b; Hauck, 1980), only three out

of thirty time-depth combinations showed increases and two of these occurred below 60 cm in depth (Table 6-1). In one case soil NH_4^+-N concentrations were reduced by DCD application. Most nitrification inhibition activity by DCD would be expected in the upper 30 cm of the soil. The reasons for this activity not being observed in the surface soil may have included confounding effects of DCD on immobilization and mineralization (Smirnov et al. 1972b), DCD induced increases in NH_3 volatilization (Rodgers, 1983), the priming effect of fertilizer N on soil organic N mineralization (Walters and Malzer, 1990b), and extreme variability in NH_4^+-N concentrations. Inhibiting activity may have been greater below 60 cm of depth because the DCD appeared to move downward with NH_4^+ in the soil and because the low organic carbon concentration in the subsoil likely minimized immobilization and mineralization effects.

Application of DCD decreased soil NO_3^--N concentrations in fifteen out of twenty time-depth combinations during the first four samplings (Figures 6-8 to 6-11 and Table 6-2). Several of these decreases were of large magnitude. No increases in soil NO_3^--N concentration were observed on any of these dates. With the last two samplings (Figures 6-12 and 6-13), however, DCD increased soil NO_3^--N concentrations in one out of ten time-depth combinations. When all of the soil NO_3^--N in the measured profile was considered together (Figure 6-14), DCD decreased NO_3^--N

concentrations on four out of six sampling dates (Table 6-2). Three of these decreases were of large magnitude, and all occurred during the first 60 days.

The SIN concentrations were increased by DCD application in only one case, and that increase was small (day 81, Table 6-3). In contrast, with eight out of thirty time-depth combinations, DCD application resulted in decreases in soil inorganic N concentration. Five of these eight were of large magnitude and all of the eight occurred during the first 60 days after fertilizer application. Decreases in SIN concentrations with increases in DCD rate occurred because substantial reductions in NO_3^--N concentrations were not balanced by increases in NH_4^+-N concentrations. Such negative effects on soil inorganic N are certainly not likely to be favorable for crop plant growth.

The SIN concentrations for the whole profile were very high, considering that 200 kg ha^{-1} of urea- and DCD-N was applied. Calculated total NH_4^+-N ha^{-1} values were as high as 400 kg ha^{-1} on day 14 while calculated NO_3^--N values were as high as 300 kg ha^{-1} on day 60. The same formula was used to calculate kg soil DCD ha^{-1} in the 1.22 m profile as was used for soil inorganic N, and the resulting DCD values were less than the amounts applied. When the soil inorganic N values for the unfertilized control were subtracted from those for the fertilized treatments (data not shown), the magnitudes were still very high. A likely explanation for this was a

priming effect on mineralization of organic soil N stimulated by application of the urea-N.

Such an effect has been proposed by Alexander (1977), Broadbent and Nakashima (1971), Kissel et al. (1977), Legg et al. (1971), and Westerman and Kurtz (1973). Walters and Malzer (1990b) observed a priming effect that was of greater magnitude than previously observed by other workers. They also observed that this effect can cause discrepancies between the ^{15}N and difference methods for quantifying leaching and plant uptake of fertilizer N. They concluded that this was because of the confounding effects of N immobilization and mineralization. Smith et al. (1989) observed that soil metabolism of organic N (immobilization and mineralization) is regulated by the concentration of soil inorganic N. They found that this effect was transitory, however, and had little long-term effect on mineralization or assimilation of the C contained in organic N.

Figure 6-21 shows some rather peculiar patterns for SIN concentration. Soil inorganic N concentration decreased from day 14 to day 31, increased until day 60, then declined rapidly. The shape of these curves was a result of two processes. Soil NH_4^+-N concentrations decreased steadily as NH_4^+-N was leached, immobilized, nitrified, and possibly volatilized to NH_3. Soil NO_3^--N concentrations increased to a maximum on day 60 due to nitrification of fertilizer N possibly combined with nitrification of mineralized organic

N. This NO_3^--N maximum was followed by a rapid decrease in the second half of the season due to leaching. In the first two samplings, a logical pattern of DCD effect was not present due to variability in the NH_4^+-N data and possible nonlinear DCD rate effects on immobilization and mineralization. The decrease from the first to the second sampling date, and subsequent increase with the next two sampling dates, could not have been due to breakdown of DCD and release of DCD-N (DCD contains 66% N). This is because the same pattern occurred with the zero DCD treatment and the unfertilized control.

This increase in SIN concentration may have been indirectly due to rather low rainfall amounts from 20 to 75 days after fertilizer application. During this time only 43 cm of rainfall occurred and most of this fell on day 53. An additional contributing factor may have been the disking of the soil for weed control. Soil cultivation normally results in a temporary increase in mineralization of soil organic N (Alexander, 1977). Even under environmentally controlled and undisturbed conditions, however, Mohamad (1985) observed substantial fluctuations in inorganic N concentrations when NH_4^+-N and DCD were applied to soil.

Reddy (1964a), in incubation studies with DCD and $(NH_4)_2SO_4$ in a Lakeland sand (Quartzipsamment) from Georgia, found that 25 mg kg^{-1} DCD inhibited nitrification for up to 90 days, with some inhibition still occurring after 150

days. Ten mg kg-1 DCD also had some inhibiting effect (Reddy, 1964a). In our study, the soil NO_3^--N (Table 6-2) and NO_3^--N/NH_4^+-N ratio data (Table 6-4) indicate that high rates of DCD (20-60 kg ha^{-1}) inhibited nitrification in a Lakeland fine sand for at least 81 days but less than 116 days.

In this Lakeland fine sand, even though DCD was effective in inhibiting nitrification, it did not increase the total soil inorganic N in the profile relative to the control. This means that even in a deep sandy soil receiving average rainfall and overhead irrigation, nitrification inhibition did not improve the efficiency of surface incorporated urea as a source of N. Though no data was collected to show this, it is quite possible that these observations were due to inhibitor-induced increases in biological immobilization of fertilizer NH_4^+ as noted by Smirnov (1968), Smirnov et al. (1968; 1972a, 1972b; 1973), Juma and Paul (1983), Ashworth et al. (1984), Norman et al. (1989), and Walters and Malzer (1990a, 1990b). Contributing factors may also have included the high N rate used, the priming effect of fertilizer N on N mineralization (Walters and Malzer, 1990b), and volatilization of NH_3 (Rodgers, 1983).

Soil DCD

The DCD concentration at the 0 to 15 and 15 to 30 cm soil depths remained fairly stable for at least the first 46 days after surface application, though a gradual reduction

occurred with the 60 kg ha^{-1} DCD treatment. Initially the DCD concentration at the 15 to 30 cm depth was about the same as that at the 0 to 15 cm depth. This can be attributed largely to mixing of these two soil depths by disking.

Early in the study, small amounts of DCD leached below the 15 to 30 cm depth. Leaching down to the 30 to 61 cm depth became more substantial by day 46. Substantial amounts of DCD had reached the 30 to 61 cm depth by day 60 with lesser amounts reaching the 61 to 91 cm depth. Meanwhile, concentrations in the top soil were lower by this time. After 60 days, soil concentrations of DCD dropped rapidly. Considering the NO_3^--N concentrations observed in the subsoil, this was most probably due more to decomposition than leaching.

By the 81st day DCD concentrations at all depths were fairly low and spread more or less evenly throughout the profile. By day 116 the DCD concentrations were generally a half an order of magnitude less than they were at day 81. Most of this remaining DCD was in the lower depths since it had decomposed in and/or leached out of the topsoil. These data confirm the conclusion of Graetz et al. (1981), that DCD was quite stable in deep sandy soils of North Florida under field conditions.

The increase in total soil DCD with the 46 and 61 day samplings with the 40 and 60 kg ha^{-1} DCD rates, was peculiar and coincided with an increase in total inorganic N at those

dates. This pattern may have been due to upward movement of DCD from below the measured portion of the profile during a period of low rainfall. Graetz et al. (1981) observed a similar increase in soil DCD concentration.

Bock et al. (1981) observed separation between DCD and NH_4^+ as they were leached down a soil column in the laboratory. They did not observe this in the case of urea, however, since DCD and urea moved with the soil solution at about the same rate. In our study urea movement was not measured since under field conditions, it was likely to have hydrolyzed within a few days of application. If one examines the movement (change in concentration with depth over time) of NH_4^+-N in Figures 6-1 to 6-6 and the movement of DCD in Figures 6-23 to 6-28, it can be concluded that in this study the bulk of the DCD did not separate from the bulk of the NH_4^+ in the soil.

CHAPTER 8
CONCLUSIONS

Plant Yield/N Content and Soil N and DCD

The nitrification inhibitors did not increase potato yields except with the 134 kg ha^{-1} N rate in the one year-location combination where they increased inorganic N levels in the soil. In that year-location combination, severe N leaching and low yields for all treatments were observed. The inhibitors did, however, increase leaf N concentration at flowering in three out of four year-location combinations. Increases in DCD rate resulted in increases in several plant parameters, though in some cases only at certain N rates. These parameters included the proportion of marketable yield that was grade A, tuber N concentration, total biomass, and total N uptake. Application of DCD led to decreases in specific gravity and plant shoot N concentration in one year-location combination each. An increase in nitrapyrin rate from 0.56 to 1.12 kg ha^{-1} resulted in increases in tuber yield and several other plant parameters with the 134 kg ha^{-1} N rate in the one test where severe leaching was observed.

When DCD and nitrapyrin inhibited nitrification, they generally did not increase inorganic N levels in the potato

rooting zone, but simply changed the ratio between NO_3^- and NH_4^+ N forms. This was the primary reason why the nitrification inhibitors usually did not increase potato crop yields. In the one test where inhibitors did increase soil inorganic N concentrations, these concentrations were extremely low due to a previously un-described mechanism of fertilizer salt loss. This mechanism involves a very rapid downward movement of nearly all fertilizer salts due to a difference in water density.

Potato yields with the DCD treatments were higher than those with nitrapyrin treatments in three of five year-location combinations. These differences were usually attributable to differences in soil NO_3^--N or total soil inorganic N concentrations. Tuber specific gravity values, however, were higher with nitrapyrin than with DCD in three of five tests. No explanation can be offered as to why tuber specific gravity values were higher with nitrapyrin than with DCD. At the rates applied in this study, DCD and nitrapyrin were about equally effective as inhibitors of nitrification. Soil inorganic N concentrations were higher with the treatment where one-third of applied N was IBDU-N, than with the inhibitor treatments in the middle and late parts of the growing season. In some cases favorable effects of IBDU on soil inorganic N concentrations resulted in increases in tuber yield and other plant parameters.

Nitrogen and inhibitor rate and IBDU effects on plant response parameters could in most cases be attributed to the effects of these treatments on soil inorganic N concentrations. This was particularly true with the sum of NH_4^+-N and NO_3^--N concentrations. Most exceptions to this direct relationship occurred in 1984 at Hastings where yields were low for reasons other than soil inorganic N concentrations.

Urea and DCD Applied to a Fallow Quartzipsamment

In the fallow Quartzipsamment study DCD had an inhibiting effect on nitrification in all or part of the 1.22 m profile on all but the last sampling date (day 116). All DCD rates inhibited nitrification for at least 60 days. Nitrification was inhibited for up to 81 days with the 40 and 60 kg ha^{-1} DCD rates. In general, DCD application lowered soil NO_3^--N levels to a greater extent than it raised NH_4^+-N levels. Thus, DCD generally decreased the total amount of inorganic N in the soil rather than increased it.

With urea as the N source, NH_4^+ and DCD moved downward in the soil profile at about the same rate. Nitrate leaching was reduced by DCD application for approximately 60 days. Concentrations of DCD incorporated with urea into the surface 15 cm of the soil, remained relatively stable for 46 days after application. A substantial portion of the DCD remaining at 60 days had leached to 45 cm. Most of this DCD

apparently decomposed in the upper 60 cm of soil after about 60 days, with the remainder leaching deep into the profile. After 60 days only 1 mg DCD kg^{-1} remained in the surface soil with the lowest DCD application rate while 4 mg kg^{-1} soil persisted with the two higher application rates. Only a very small amount (< 0.25 mg DCD kg^{-1} soil) persisted in the soil after 116 days, with this having leached to a depth of 1.2 m. The residence half times of DCD in the 1.2 m profile were 61 (r^2 = -0.9697), 66 (r^2 = -0.7487), and 63 (r^2 = -0.9524) days for the 20, 40, and 60 kg ha^{-1} DCD rates, respectively.

General Conclusions

When nitrification inhibitors increase crop yields, this can be attributed to their favorable effects on total soil inorganic N concentrations rather than the lack of leaching rainfall. Because of inhibitor effects on N immobilization and mineralization in soil, inhibitors usually do not increase soil inorganic N concentrations unless N is applied below recommended rates and leaching of fertilizer N is severe.

Nitrification inhibitors can be recommended for potato production in Northeast Florida if N is applied at less than recommended rates and if sub-surface irrigation systems are unreliable in their control of water table levels. If N fertilizer rates are equal to or greater than those recommended or if irrigation and drainage systems provide

reliable control of water table levels, then nitrification inhibitors can not be recommended for potato production in Northeast Florida.

Recommendations For Future Research

Ashworth (1986) recommended that long term studies with nitrification inhibitors and ^{15}N labeled fertilizer should be conducted in the field to assess the effect of inhibitors on N immobilization and other components of the N cycle. This year, Walters and Malzer (1990a, 1990b) published such a study. If this type of study is repeated, several rates of nitrification inhibitor should be included rather than split N applications. Such studies should also monitor the effects of inhibitor rates on NH_3 volatilization and total soil inorganic N concentrations.

If possible, several soils should be used in such studies. Soils should vary in pH, texture, and organic C and N content and represent several soil taxonomic orders. It should not be necessary to conduct a great deal of research comparing several types of nitrification inhibitor. This is because at comparable effective concentrations, most nitrification inhibitor compounds appear to have similar effects on soil N transformations.

McCormick et al. (1984) and several European workers have observed much larger crop yield increases due to nitrification inhibitors with manure than with synthetic N fertilizers. Thus, studies should be conducted on the

interaction between organic amendment rates and nitrification inhibitor rates.

Separate studies should be conducted on effects of inhibitors on NH_3 volatilization from NH_4NO_3 and urea applied to sandy and fine textured, and acid and calcareous soils. An ^{15}N labeled DCD should be produced with the ^{15}N occurring on different specific positions in the DCD structure. Biochemical studies could then be conducted on the mechanism of nitrification inhibition by DCD and the breakdown and fate of DCD in soil. It would be worthwhile to assess the ability of a variety of native and cultured nitrifying organisms to acquire a tolerance for various nitrification inhibitors.

Research should be carried out for the purpose of improving the analytical method for DCD in soil extracts. Such a study should determine the effects of (1) time of equilibration of naphthol reagent with DCD solutions of known concentrations; (2) degree of mixing of naphthol reagent and DCD standard solutions; (3) filtration v centrifugation of naphthol reagent; (4) Ca^{2+}, K^+, and NO_3^- concentrations of soil extracts on accuracy of the method; (5) O_2 concentration of naphthol reagent on accuracy of the method; (6) alternative complexing reagents; (7) alternative soil extractants; (8) varying pH of soil extractants; and (9) addition of reducing agents to naphthol reagent.

Other methods for analysis of DCD in soil extracts should be pursued, including high pressure liquid

chromatography (HPLC) of volatile DCD derivatives, gas chromatography, UV spectrophotometry, and thin layer chromatography. Subsequent to these studies, adsorption isotherms and degradation kinetics for DCD should be determined for a variety of soils. Soil retention characteristics of DCD could be determined by a continuous flow technique as proposed by the late J.G. Fiskell.

There are in the literature many studies of inhibitor effects on yield of crops in the field. There is, however, insufficient reported research in the literature on the effects of nitrification inhibitors on environmental quality parameters such as long term total N leaching into surface and subsurface drainage systems. Such studies should be conducted with ^{15}N on the same soils for at least four years. Studies should be conducted on the effects of inhibitor, N, and organic C rates and environmental conditions on soil and fertilizer N immobilization, mineralization, leaching, "aerobic" denitrification, and gaseous N losses.

Nitrification inhibitors can be used as tools in various types of soil N cycle studies in the field, greenhouse, or laboratory. Dicyandiamide, because of its physical and chemical properties, is a useful nitrification inhibitor for these types of studies.

APPENDICES

APPENDIX A
SOIL CHARACTERIZATION

Potato soils. The results of the soil characterization analyses shown in Table 3-2, indicate that all of these soils are quite sandy as is characteristic of most Florida soils, with sand contents exceeding 90% in all but the Millhopper sand which has approximately 84% sand. All have silt contents of 6% or less except the Millhopper sand with approximately 11%. Clay contents are in all cases less than 5%. Organic carbon contents in the top soils are all fairly low with the Plummer fine sand having the least and the Millhopper sand the most. Organic N contents in the top soils are less than 0.07% except in the case of the Millhopper sand with almost 0.13% organic N. Cation exchange capacities are all 4 cmol kg^{-1} or less except in the Millhopper sand with approximately 8 cmol kg^{-1}. These low CEC values are to be expected since the sand contents are so high. The pH values are all below 5.5 which is favorable for potato production. Lime is used sparingly for potato production in Florida, thus the pH values reported here are probably not much higher than the native pH values for these soils.

The Millhopper sand used in 1983 at Gainesville stands out as being a more fertile soil than the others. This is likely because of its greater silt content and the fact that it had been cleared from forest for only a few years. As a result of these factors, this soil was much higher in organic carbon, total N, and CEC than the other soils.

Fallow soil. The properties of the Lakeland fine sand shown in Table 3-2 indicate that the sand content is fairly consistent with depth while the clay content tends to increase slightly with depth. Silt, organic C and organic N contents as well as CEC and pH decline steadily with depth. These data are normal for Typic Quartzipsamments in Florida.

APPENDIX B
SAMPLE ANALYSIS OF VARIANCE TABLE

Table B-1. Analysis of variance table for plant response parameters in the studies with potato.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	20	2428.7	121.4	6.00	0.0001
Error	51	1031.6	20.2		
Corrected Total	71	3460.3			
Block	3	1804.0		29.73	0.0001
DCD Linear (DCD L)	1	3.6		0.18	0.6741
DCD Quadratic (DCD Q)	1	12.3		0.61	0.4392
Nitrapyrin Rate (Nty R)	1	0.4		0.02	0.8904
DCD v Nty	1	80.2		3.96	0.0519
IBDU v DCD and Nty (IBDU v Ih)	1	0.3		0.02	0.9010
N Rate Linear (NR L)	1	212.9		10.53	0.0021
N Rate Quadratic (NR Q)	1	74.1		3.66	0.0612
DCD L X NR L	1	0.3		0.01	0.9032
DCD L X NR Q	1	28.8		1.43	0.2381
DCD Q X NR L	1	11.1		0.55	0.4615
DCD Q X NR Q	1	13.2		0.65	0.4226
Nty R X NR L	1	73.1		3.61	0.0630
Nty R X NR Q	1	19.1		0.94	0.3357
DCD v Nty X NR L	1	30.8		1.52	0.2231
DCD v Nty X NR Q	1	6.7		0.33	0.5688
IBDU v Ih X NR L	1	0.5		0.03	0.8705
IBDU v Ih X NR Q	1	10.0		0.49	0.4860

Dependent Variable--Marketable Potato Yield at Gainesville in 1984.

APPENDIX C
INORGANIC N CONCENTRATIONS IN SOILS PLANTED TO POTATO AS AFFECTED BY SELECTED TREATMENTS

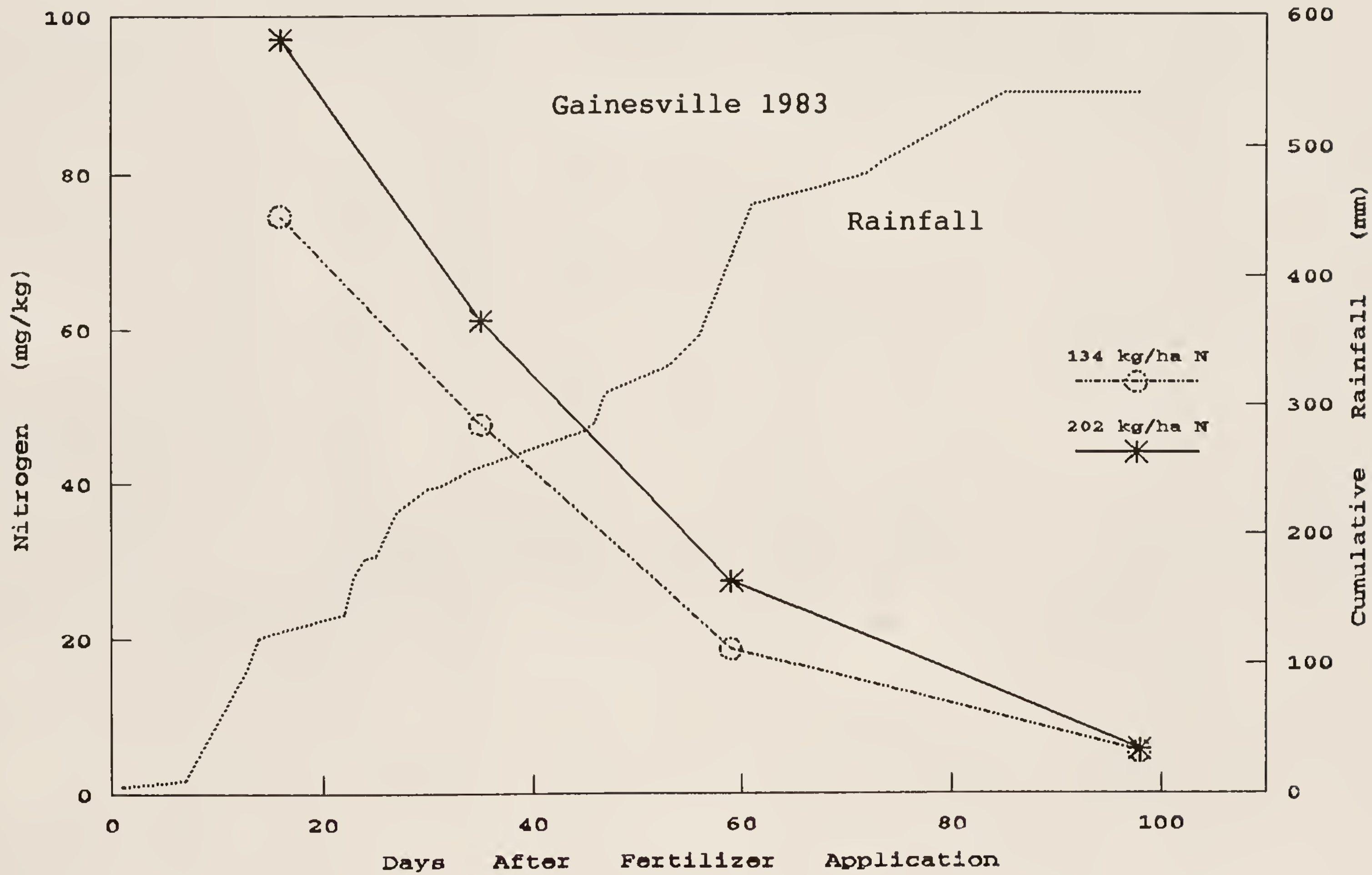

Figure C-1. Effects of N rate on soil inorganic N concentration (Gainesville, 1983).

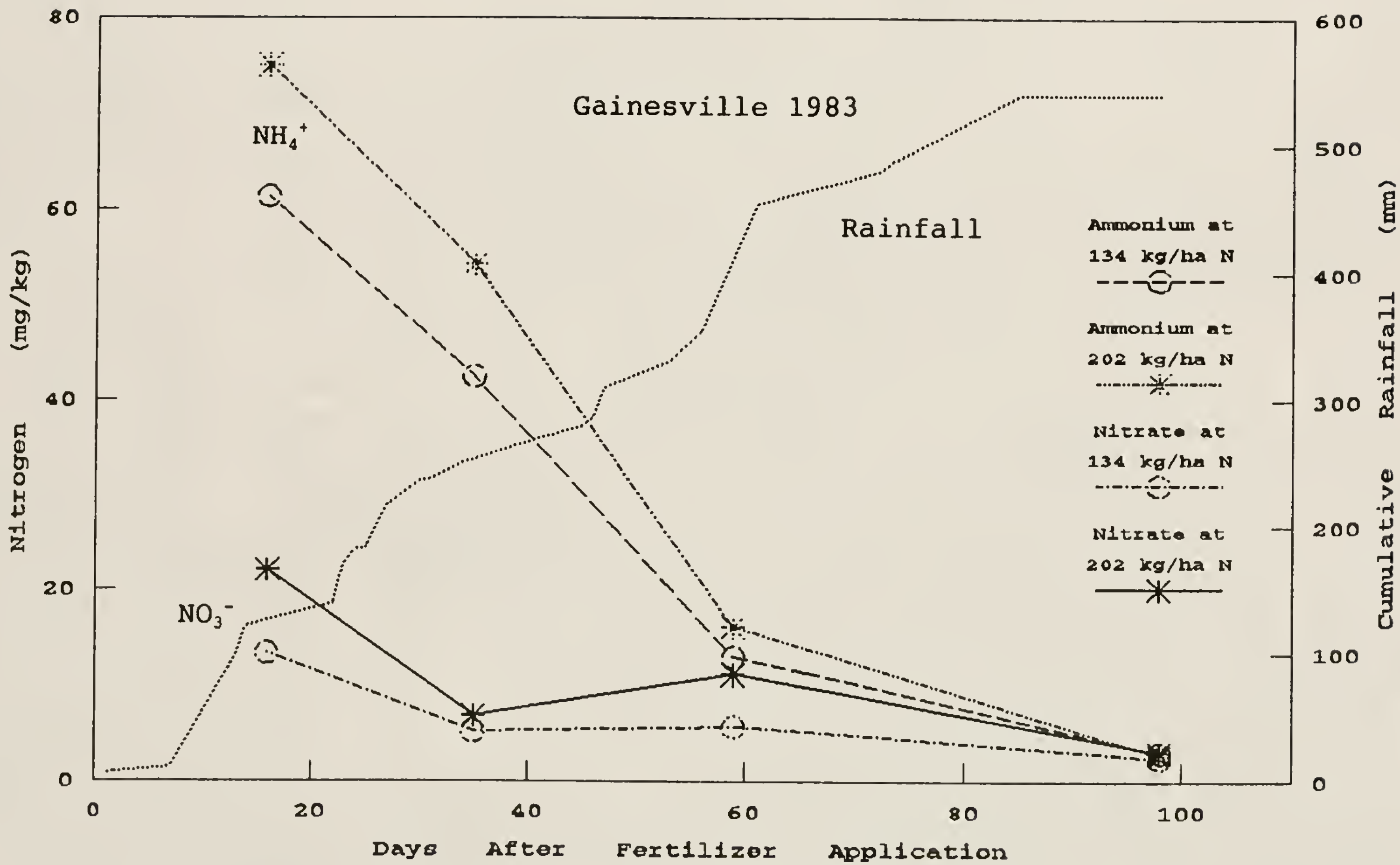

Figure C-2. Effects of N rate on soil NH_4^+ and NO_3^- concentrations (Gainesville, 1983).

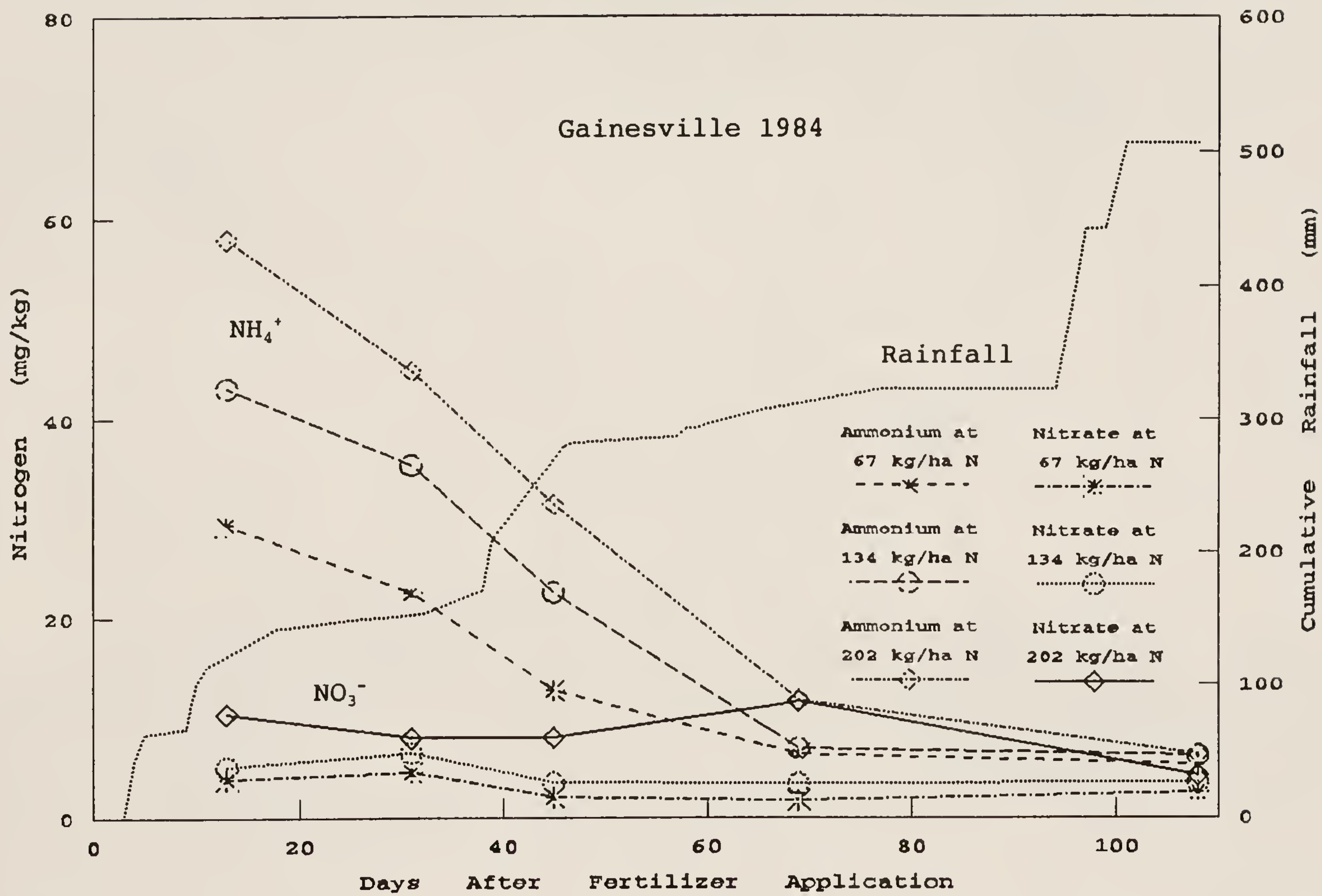

Figure C-3. Effects of N rate on soil NH_4^+ and NO_3^- concentrations (Gainesville, 1984).

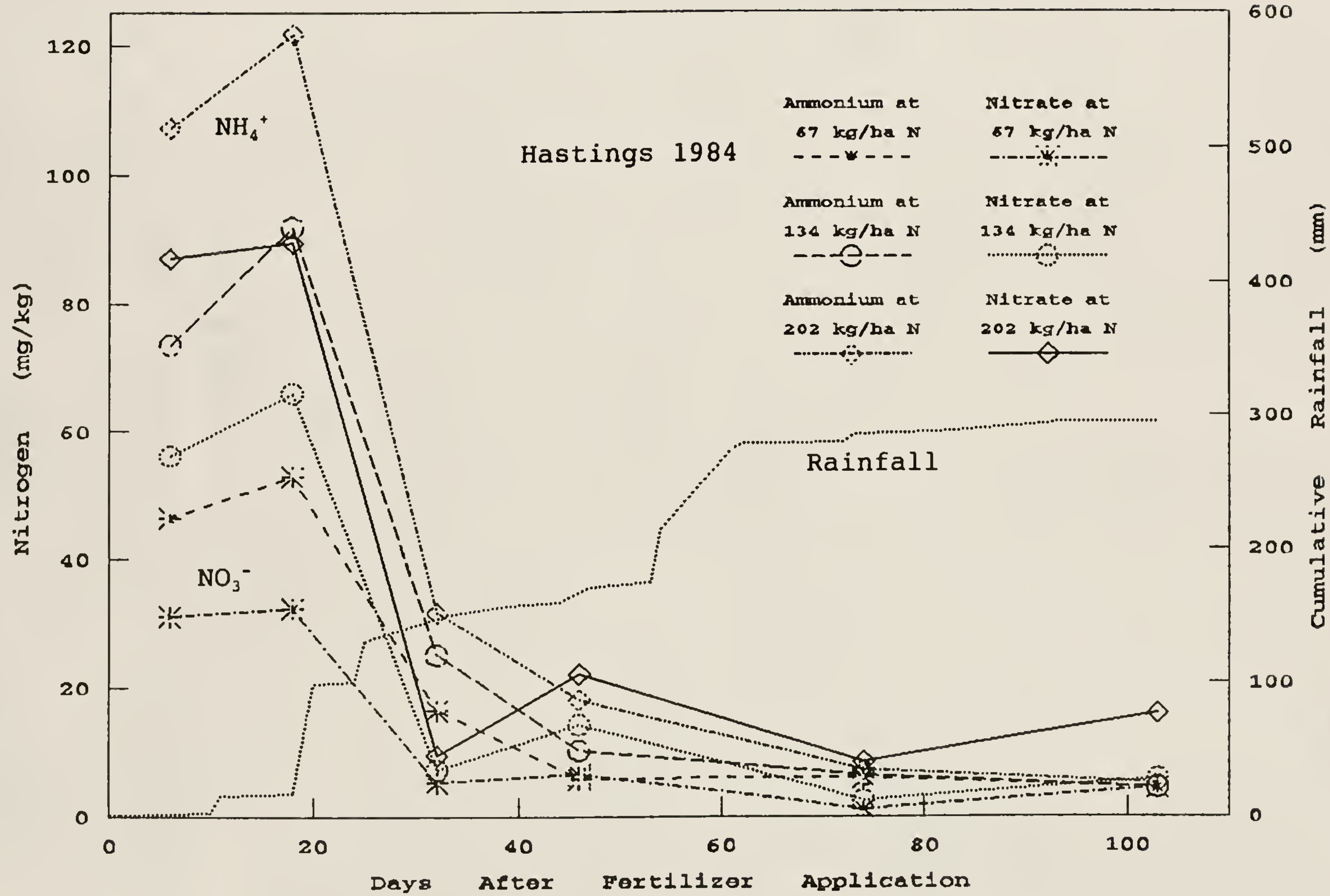

Figure C-4. Effects of N rate on soil NH_4^+ and NO_3^- concentrations (Hastings, 1984).

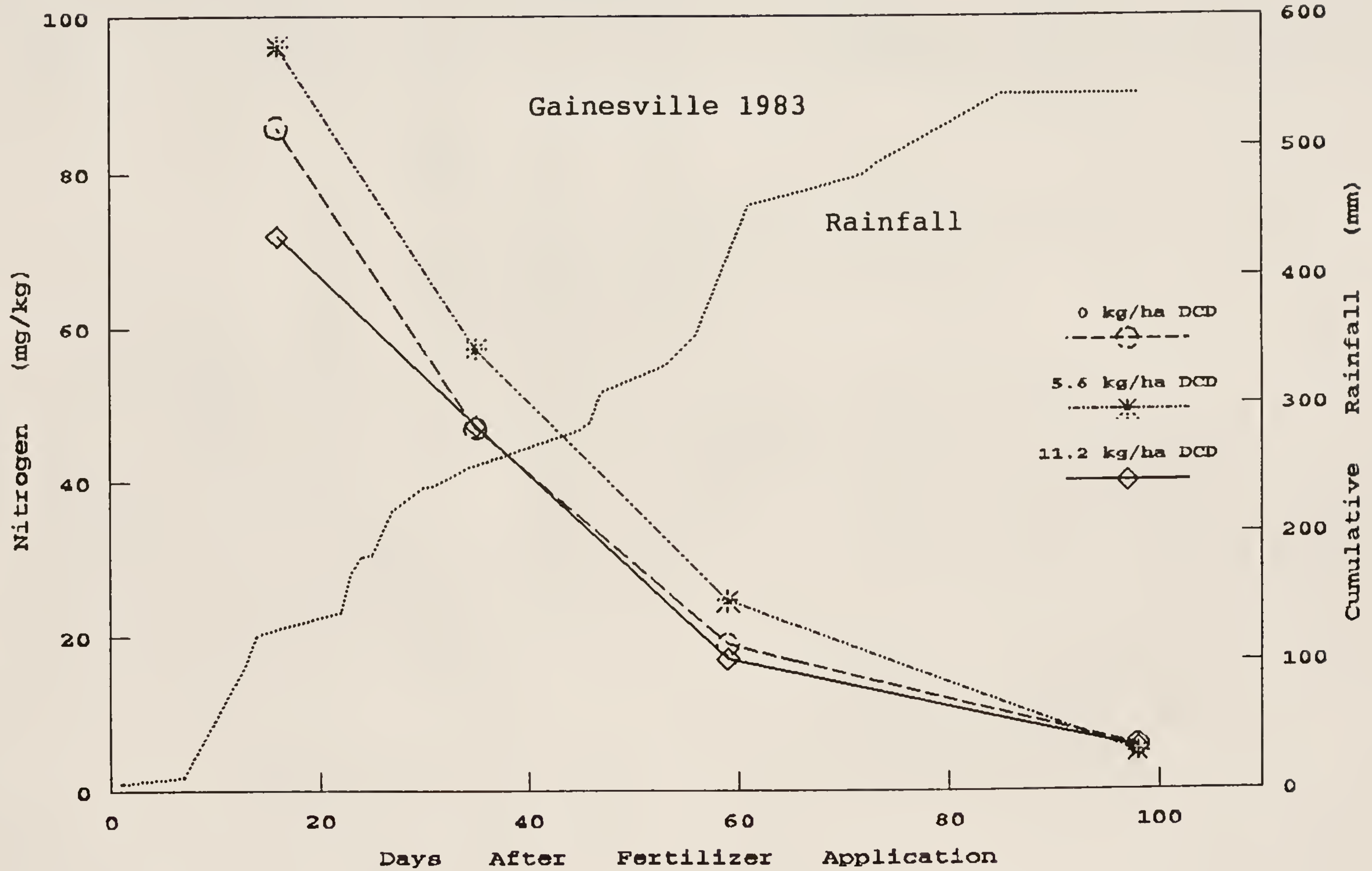

Figure C-5. Effects of DCD rate on soil inorganic concentration N (Gainesville, 1983).

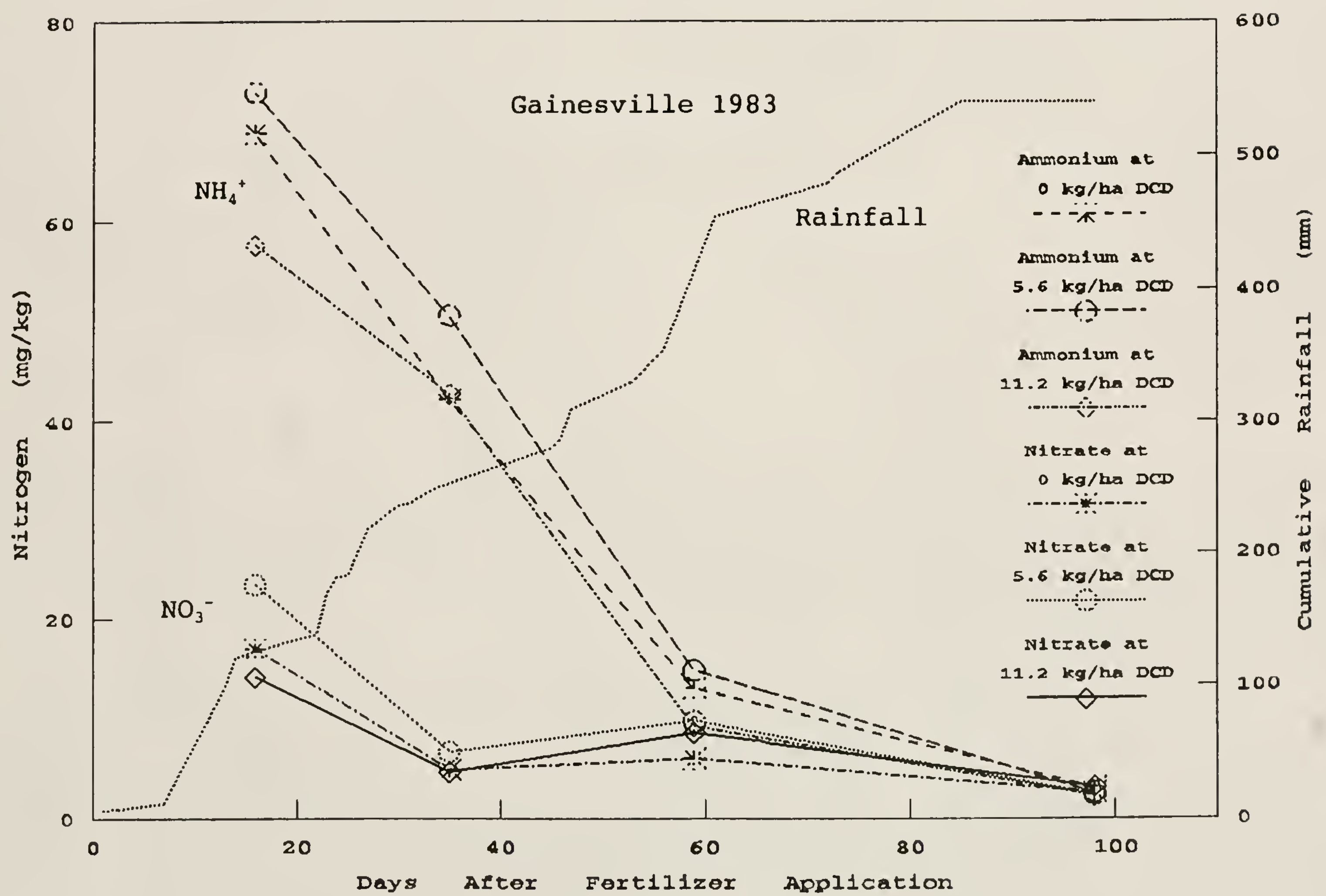

Figure C-6. Effects of DCD rate on soil NH_4^+ and NO_3^- concentrations (Gainesville, 1983).

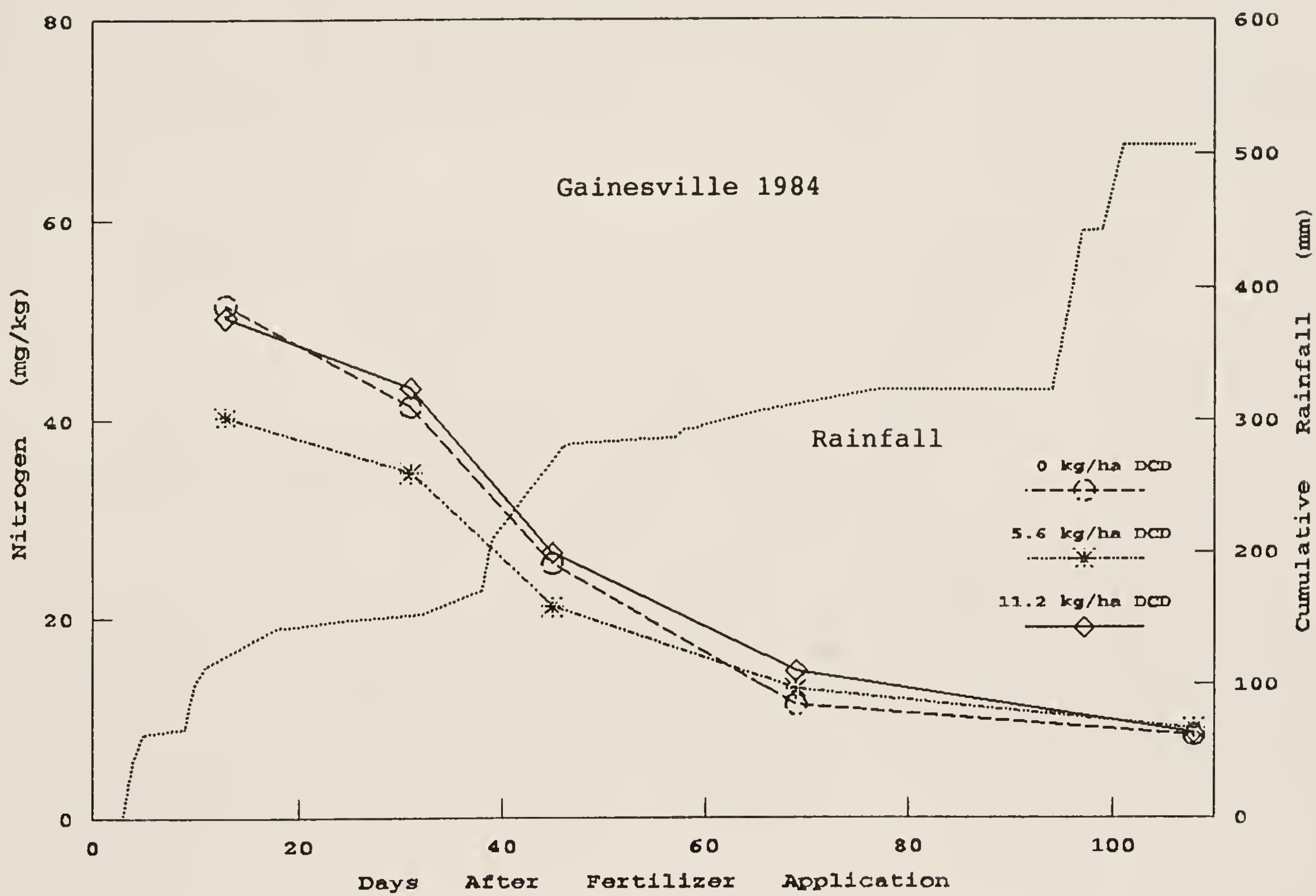

Figure C-7. Effects of DCD rate on soil inorganic N concentration (Gainesville, 1984).

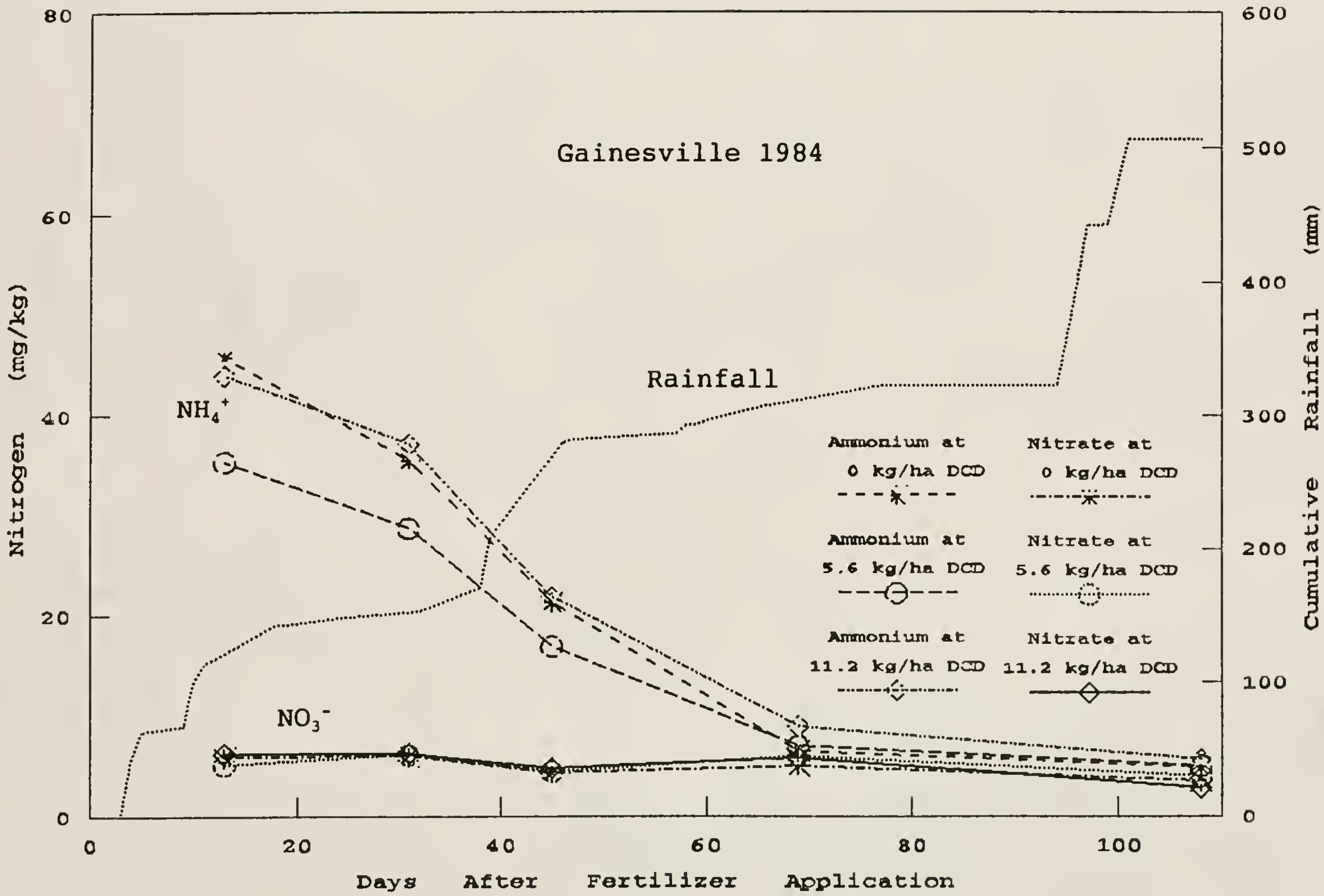

Figure C-8. Effects of DCD rate on soil NH_4^+ and NO_3^- concentrations (Gainesville, 1984).

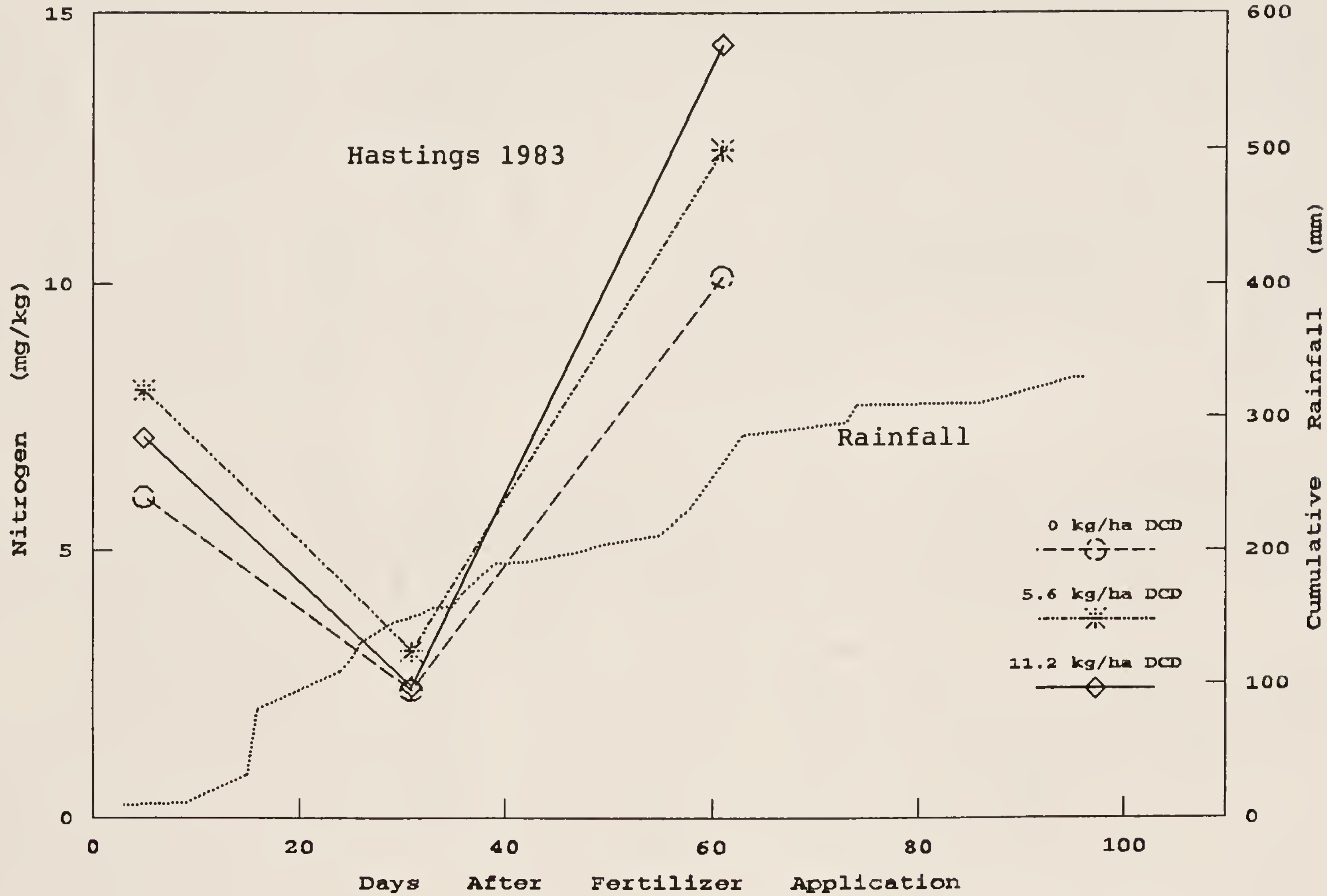

Figure C-9. Effects of DCD rate on soil inorganic N concentration (Hastings, 1983).

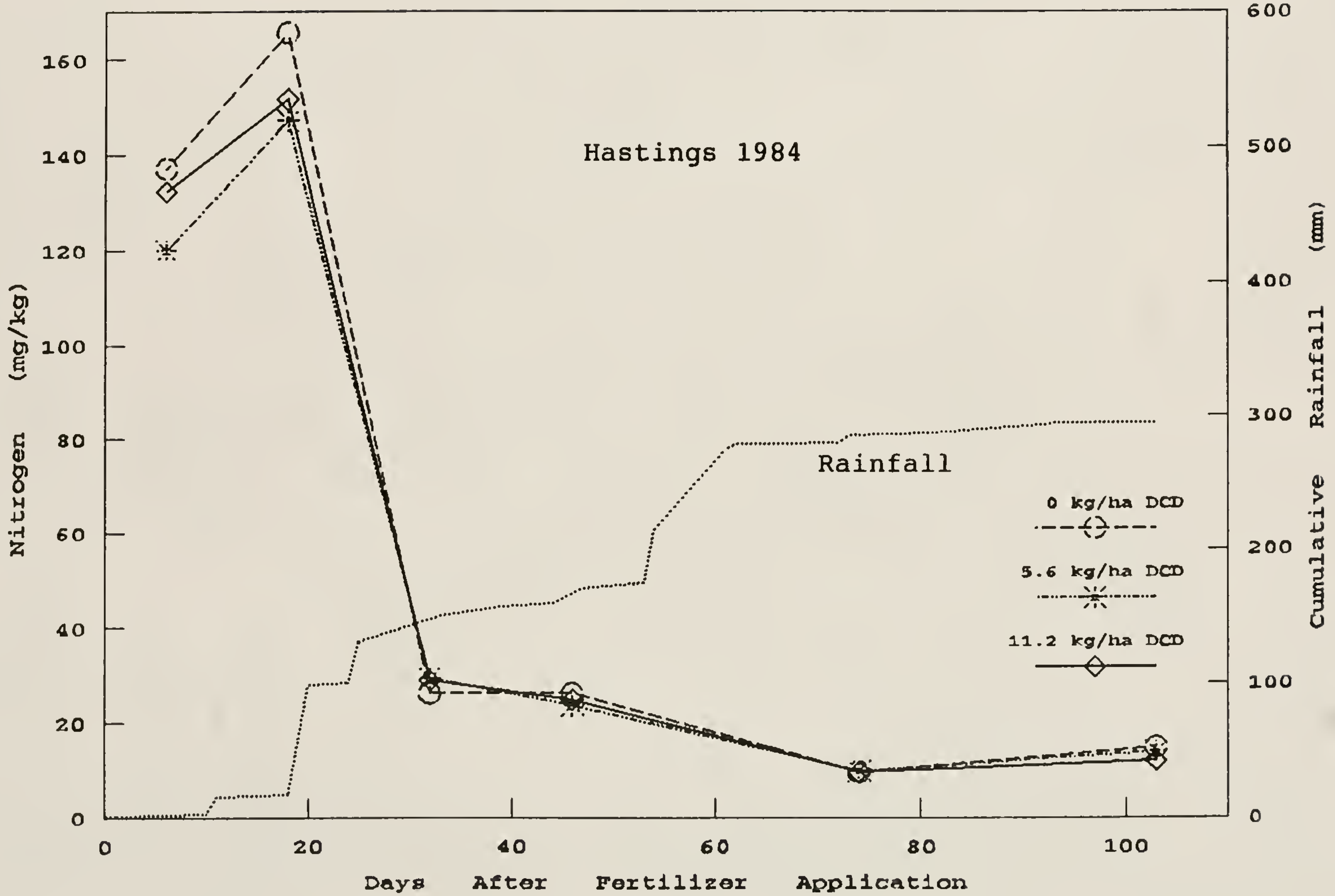

Figure C-10. Effects of DCD rate on soil inorganic N concentration (Hastings, 1984).

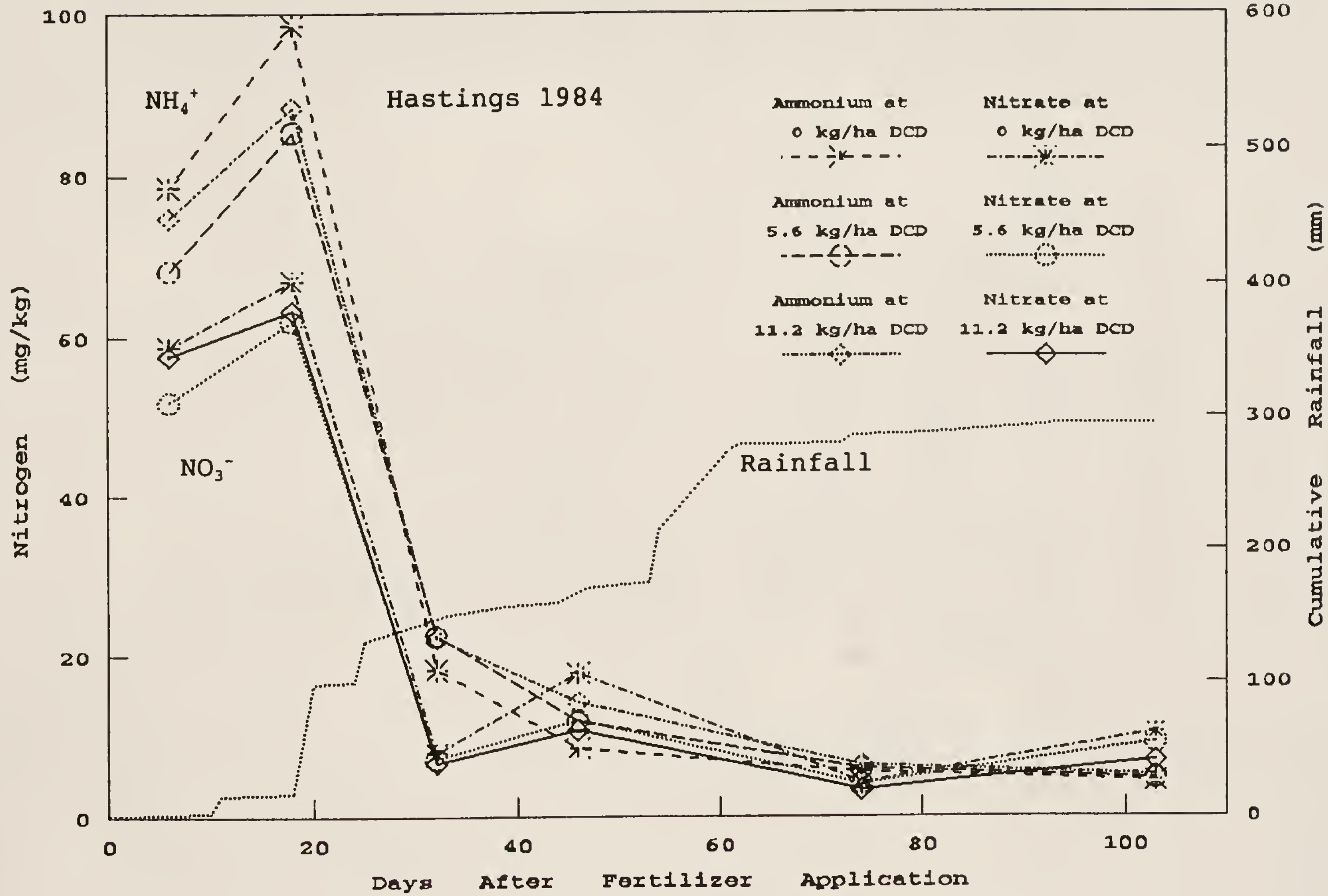

Figure C-11. Effects of DCD rate on soil NH_4^+ and NO_3^- concentrations (Hastings, 1984).

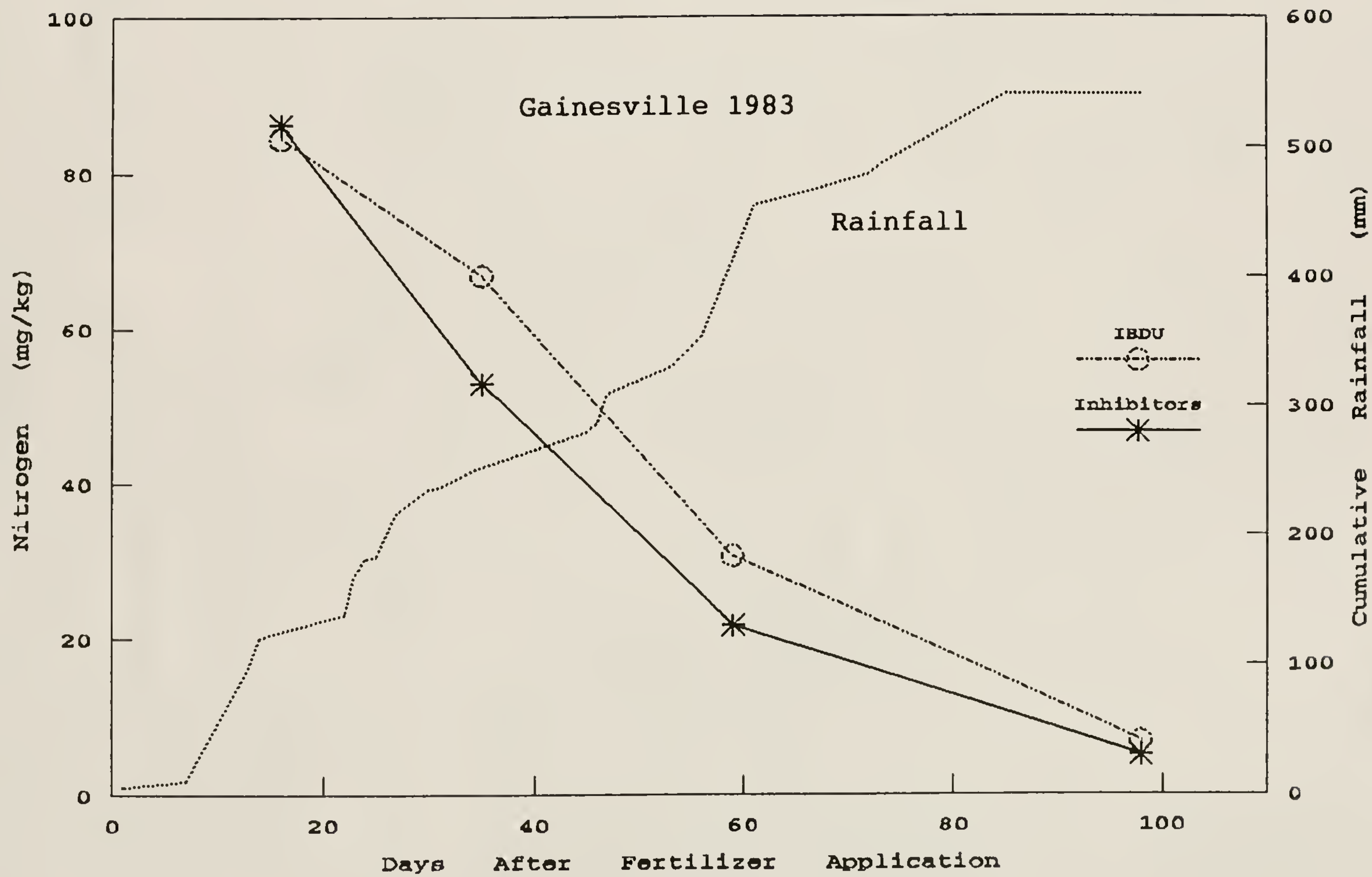

Figure C-12. Contrast of IBDU and inhibitor effects on soil inorganic N concentration (Gainesville, 1983).

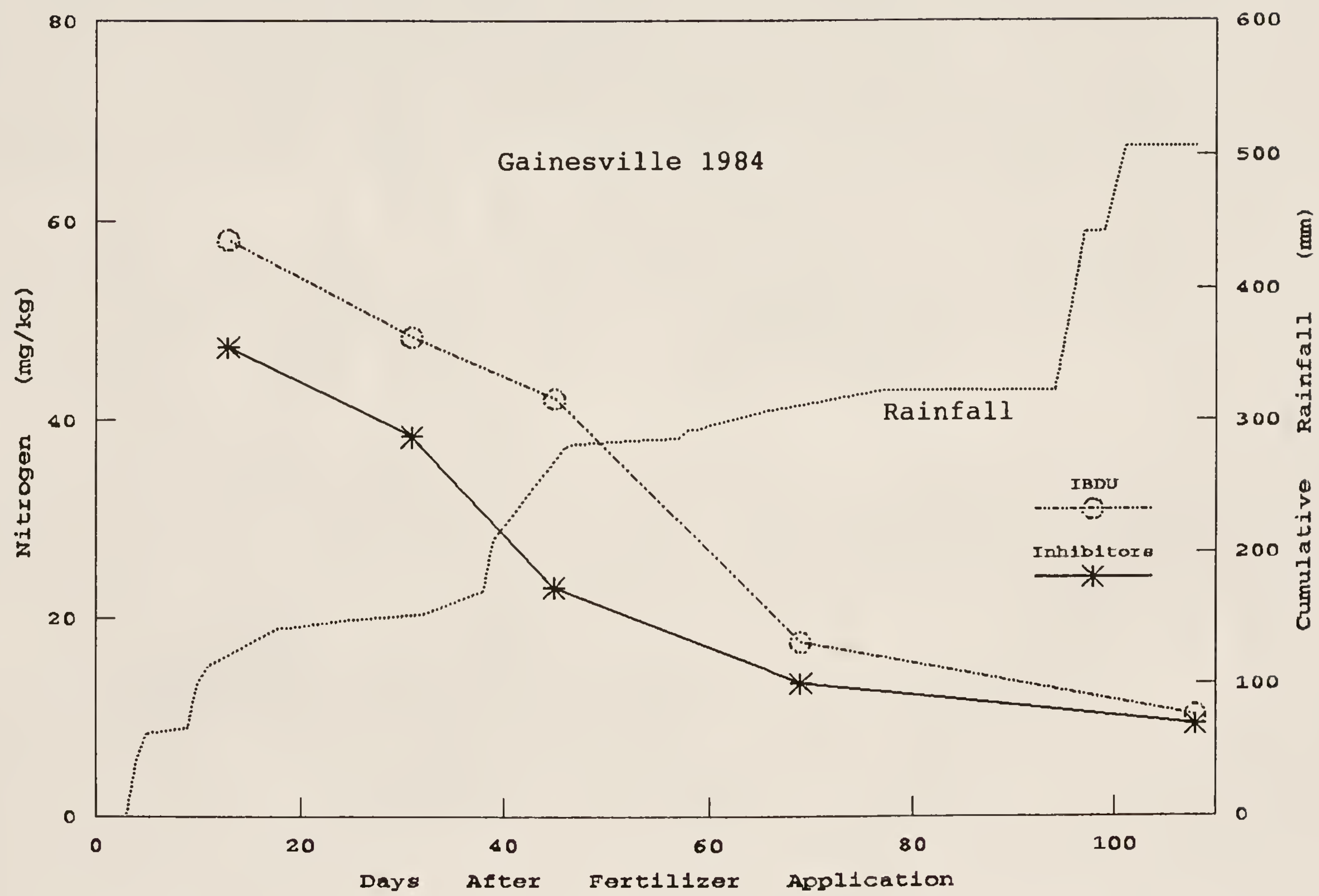

Figure C-13. Contrast of IBDU and inhibitor effects on soil inorganic N concentration (Gainesville, 1984).

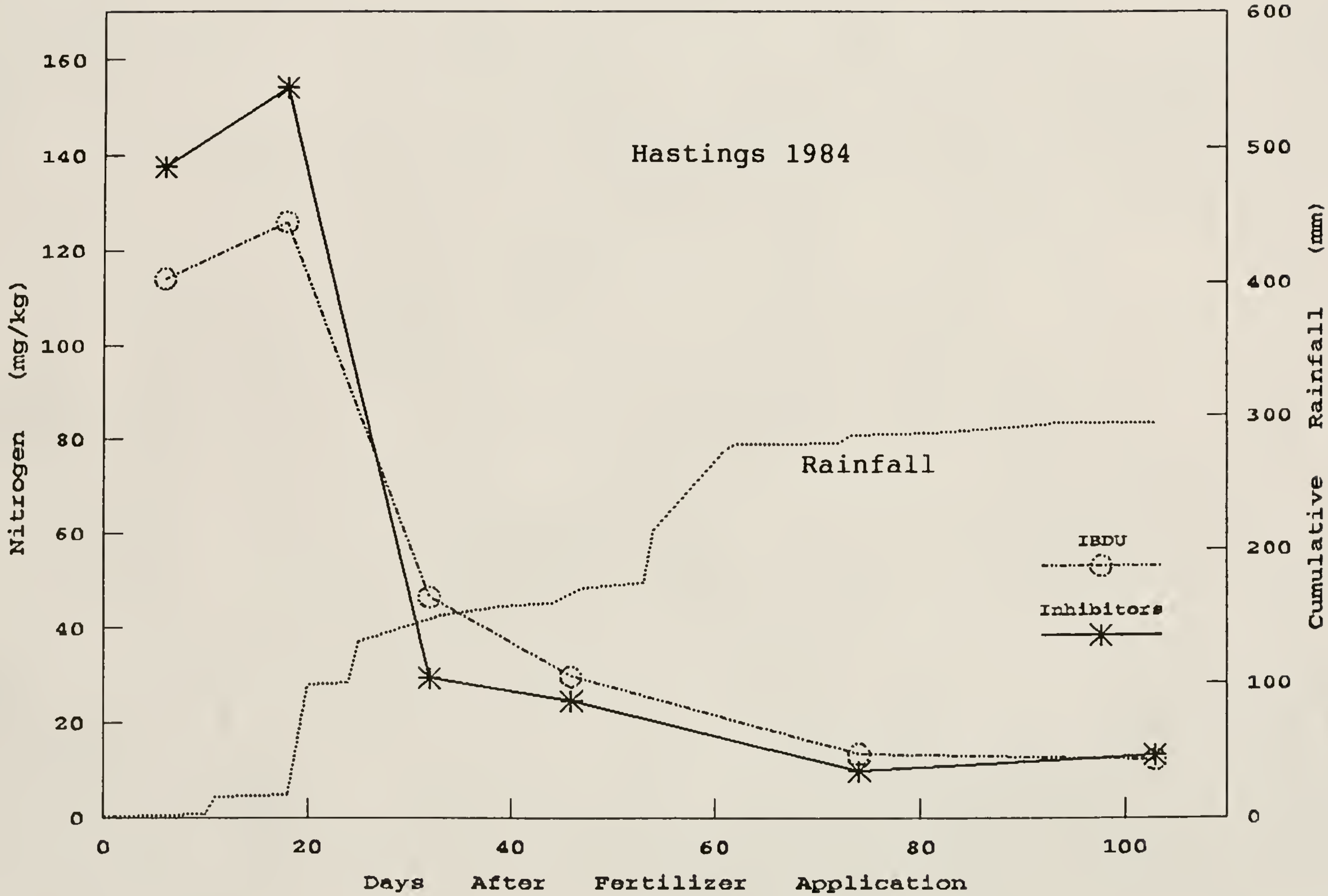

Figure C-14. Contrast of IBDU and inhibitor effects on soil inorganic N concentration (Hastings, 1984).

APPENDIX D
ANALYSIS OF VARIANCE OF INORGANIC N IN SOILS PLANTED TO POTATO

Table D-1. Analysis of variance of nitrogen and amendment rate effects on soil NH_4^+-N concentration (Gainesville, 1983).

Independent Variable	Days After Application				
	16	35	59	98	Mean
N Rate	**	**	x	NS	***
DCD Rate	NS	NS	NS	NS	Q*
Nty Rate	NS	NS	NS	NS	NS
DCD v Nty	NS	NS	x	NS	NS
IBDU v Ih	NS	*	*	*	*
Interactions					
DCD L X NR	NS	NS	NS	NS	NS
DCD Q X NR	NS	NS	NS	NS	*
Nty R X NR	*	NS	NS	NS	NS
DCD v Nty X NR	NS	NS	NS	NS	NS
IBDU v Ih X NR	NS	NS	NS	NS	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table D-2. Analysis of variance of nitrogen and amendment rate effects on soil NO_3^--N concentration (Gainesville, 1983).

Independent Variable	Days After Application 16	35	59	98	Mean
N Rate	**	x	***	*	***
DCD Rate	Qx	NS	NS	NS	Q*
Nty Rate	NS	NS	NS	NS	NS
DCD v Nty	NS	NS	NS	NS	NS
IBDU v Ih	NS	NS	*	NS	NS
Interactions					
DCD L X NR	NS	NS	NS	NS	NS
DCD Q X NR	NS	x	NS	NS	*
Nty R X NR	x	NS	NS	NS	NS
DCD v Nty X NR	NS	NS	NS	x	NS
IBDU v Ih X NR	NS	NS	**	x	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table D-3. Analysis of variance of nitrogen and amendment rate effects on soil NO_3^--N/(NO_3^--N + NH_4^+-N) ratio (Gainesville, 1983).

Independent Variable	Days After Application				
	16	35	59	98	Mean
N Rate	*	NS	NS	x	**
DCD Rate	NS	NS	L*	NS	L*
Nty Rate	NS	NS	NS	NS	NS
DCD v Nty	NS	NS	*	NS	x
IBDU v Ih	x	NS	NS	NS	NS
Interactions					
DCD L X NR	NS	NS	*	NS	NS
DCD Q X NR	NS	NS	NS	NS	NS
Nty R X NR	NS	NS	NS	NS	NS
DCD v Nty X NR	NS	NS	NS	NS	*
IBDU v Ih X NR	NS	NS	*	NS	x

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.01 (**) probability levels, respectively.

Table D-4. Analysis of variance nitrogen and amendment rate effects on soil NH_4^+-N concentration (Gainesville, 1984).

Independent Variable	Days After Application 13	31	45	69	108	Mean
N Rate	L***	L**	L***	L*** Q***	L*	L***
DCD Rate	Q***	Q**	Qx	L*	NS	Q***
Nty Rate	NS	NS	NS	NS	***	NS
DCD v Nty	NS	NS	NS	NS	***	NS
IBDU v Ih	***	***	***	*	NS	***
Interactions						
DCD L X NR	NS	NS	NS	NS	NS	NS
DCD Q X NR	Q*	Qx	NS	NS	NS	LxQ**
Nty R X NR	NS	L*	L**	Lx	L**	L**
DCD v Nty X NR	Lx	NS	Qx	Lx	L*	L*Q*
IBDU v Ih X NR	L*	Q***	Q**	Q*	NS	Q**

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table D-5. Analysis of variance of nitrogen and amendment rate effects on soil NO_3^--N concentration (Gainesville, 1984).

Independent Variable	Days After Application 13	31	45	69	108	Mean
N Rate	L***	L***	L***	L***	L***	L***
	Q**		Q*	Q***		Q*
DCD Rate	NS	NS	NS	NS	Qx	NS
Nty Rate	NS	NS	NS	NS	*	NS
DCD v Nty	x	NS	NS	x	x	NS
IBDU v Ih	NS	NS	*	*	***	***
<u>Interactions</u>						
DCD L X NR	NS	L***	NS	NS	NS	L**
DCD Q X NR	NS	Q*	NS	NS	NS	NS
Nty R X NR	NS	NS	NS	NS	NS	NS
DCD v Nty X NR	NS	NS	L*Q*	L**Q*	NS	L**Q**
IBDU v Ih X NR	L**Qx	NS	L*	L***Q*	NS	L***Q**

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table D-6. Analysis of variance of nitrogen and amendment rate effects on soil NO_3^--N/(NO_3^--N + NH_4^+-N) ratio (Gainesville, 1984).

Independent Variable	Days After Application 13	31	45	69	108	Mean
N Rate	L*** Q**	NS	Lx	L***	L**	L***
DCD Rate	NS	Q*	Q* Qx	L* Q*	L*	L**
Nty Rate	NS	NS	NS	NS	***	NS
DCD v Nty	NS	**	NS	NS	***	NS
IBDU v Ih	NS	*	NS	NS	***	NS
<u>Interactions</u>						
DCD L X NR	NS	L**	L*	NS	NS	NS
DCD Q X NR	L*	Q***	Qx	NS	NS	NS
Nty R X NR	Qx	NS	NS	NS	L*	NS
DCD v Nty X NR	NS	L**	L**	L**Q*	NS	L***Q*
IBDU v Ih X NR	L*	L**Q**	L**	L**	NS	L***Q**

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table D-7. Analysis of variance of nitrogen and amendment rate effects on soil NH_4^+-N and NO_3^--N concentration (Hastings, 1983).

Independent Variable	Days After Application 5	31	61	Mean
	NH_4^+-N			
N Rate	NS	NS	NS	NS
DCD Rate	NS	Qx	L*	L** Qx
Nty Rate	-	NS	NS	NS
DCD v Nty	-	NS	NS	NS
IBDU v Ih	-	NS	NS	NS
Interactions	NS	NS	NS	NS
	NO_3^--N			
N Rate	NS	*	*	**
DCD Rate	NS	NS	NS	NS
Nty Rate	-	NS	NS	NS
DCD v Nty	-	NS	NS	NS
IBDU v Ih	-	*	NS	NS
Interactions	NS	IBDU v Ih X NR *	DCD Q X NR x	DCD Q X NR **

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.01 (**) probability levels, respectively.

Table D-8. Analysis of variance of nitrogen and amendment rate effects on soil NO_3^--N/(NO_3^--N + NH_4^+-N) ratio (Hastings, 1983).

Independent Variable	Days After Application			Mean
	5	31	61	
N Rate	NS	NS	NS	NS
DCD Rate	NS	NS	L*** Qx	L*
Nty Rate	-	NS	NS	NS
DCD v Nty	-	NS	NS	NS
IBDU v Ih	-	NS	NS	NS
Interactions	NS	NS	Nty R X NR x	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), or 0.001 (***) probability levels, respectively.

Table D-9. Analysis of variance of nitrogen and amendment rate effects on soil NH_4^+-N concentration (Hastings, 1984).

Independent Variable	Days After Application 6	18	32	46	74	103	Mean
N Rate	L***	L***	L***	L***	L**	L***	L***
		Qx		Q**			
DCD Rate	NS	L*	Lx	L***	Lx	L**	NS
		Q*					
Nty Rate	NS	NS	NS	*	NS	NS	NS
DCD v Nty	*	x	NS	*	NS	NS	x
IBDU v Ih	NS	***	***	NS	***	*	NS
Interactions							
DCD L X NR	NS	LxQx	NS	L**	NS	Lx	NS
DCD Q X NR	L***	L**	NS	NS	NS	NS	L**
Nty R X NR	NS	L**	NS	NS	NS	NS	NS
DCD v Nty X NR L	NS	NS	NS	L**	NS	NS	NS
IBDU v Ih X NR L	NS	L*	L***	NS	L***	L**	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table D-10. Analysis of variance of nitrogen and amendment rate effects on soil NO_3^--N concentration (Hastings, 1984).

Independent Variable	Days After Application 6	18	32	46	74	103	Mean
N Rate	L***	L***	L***	L***	L***	L***	L***
	Q**			Q***	Q***		
DCD Rate	NS	NS	L*	L***	NS	L**	Lx
				Q*			
Nty Rate	*	*	NS	NS	NS	NS	NS
DCD v Nty	*	x	NS	**	NS	NS	**
IBDU v Ih	***	***	NS	***	*	NS	**
<u>Interactions</u>							
DCD L X NR	NS	Qx	NS	L*	NS	L*	NS
DCD Q X NR	L*	NS	NS	L*	NS	NS	L*
Nty R X NR	Qx	L**	NS	NS	LxQx	NS	NS
DCD v Nty X NR	NS	NS	Q*	Q***	NS	NS	NS
IBDU v Ih X NR	NS	L**	NS	NS	NS	NS	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table D-11. Analysis of variance of nitrogen and amendment rate effects on soil NO_3^--N/(NO_3^--N + NH_4^+-N) ratio (Hastings, 1984).

Independent Variable	Days After Application						
	6	18	32	46	74	103	Mean
N Rate	L***	L***	Qx	L***	L***	L***	L***
		Q***		Q*	Q*	Q***	
DCD Rate	NS	NS	L***	L***	L**	L***	L***
		Q*	Q**			Qx	
Nty Rate	NS	NS	x	***	NS	NS	*
DCD v Nty	NS	NS	NS	***	NS	x	***
IBDU v Ih	***	***	***	***	*	NS	NS
<u>Interactions</u>							
DCD L X NR	NS	L***	NS	Qx	L*	NS	NS
DCD Q X NR	NS	Q*	Q*	NS	NS	NS	NS
Nty R X NR	NS	NS	Qx	L*	NS	NS	Lx
DCD v Nty X NR	NS	NS	NS	Q***	NS	LxQx	Q**
IBDU v Ih X NR L	NS	Qx	NS	Q**	NS	L***	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

Table D-12. Analysis of variance of nitrogen and amendment rate effects on total soil inorganic N means for all sampling dates.

Independent Variable	Gainesville		Hastings	
	1983†	1984	1983	1984
N Rate	***	L**	*	L***
		Qx		
DCD Rate	Q*	Q***	L*	NS
Nty Rate	NS	NS	NS	NS
DCD v Nty	NS	NS	NS	*
IBDU v Ih	x	****	NS	x
Interactions				
DCD L X NR	NS	Qx	NS	NS
DCD Q X NR	**	Q*	NS	L**
Nty R X NR	NS	L**	NS	NS
DCD v Nty X NR	NS	Q**	NS	NS
IBDU v Ih X NR	NS	L**	NS	NS

Nonsignificant (NS) or significant at the 0.10 (x), 0.05 (*), 0.01 (**), or 0.001 (***) probability levels, respectively.

†See Chapter 5 for data for individual sampling dates.

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BIOGRAPHICAL SKETCH

Harris Martin was born in 1954 in Bala Cynwyd, PA. His parents are J. Stanwood Martin and M. Elizabeth Newkirk Martin, of Philadelphia. His family engaged in part time farming while operating an equipment rental business. Harris graduated from Conestoga High School in Berwyn, PA, where he was the student council president.

He earned a B.S. in Environmental Science at Antioch College, in Ohio, in 1979. While at Antioch, he participated in an environmental field program, spending a semester studying coastal environments in Georgia and Florida. He earned an M.S. degree in Plant Science at the University of Delaware, under Dr. Donald Sparks. His M.S. research concerned nonexchangeable potassium in coastal plain soils. While in Delaware, he married and started a family.

At the University of Florida, Harris conducted his Ph.D. research on nitrification inhibitors and potato. Presently, Harris is a single father with two children, Stanwood, age 6, and Rachel, age 8, of whom he has joint custody. While living in Gainesville, he has been a Cub Scout den leader, a Sunday School teacher, a computer instructor for primary grade children, and president of the local chapter of Parents Without Partners.

Harris has worked at a wide variety of positions including farm hand, salesman, assistant manager, gardener, oil exploration jug boy, warehouseman, truck driver, plant taxonomy intern, cave diver, soils consultant, and research assistant. Though most of his spare time is spent with his children, his hobbies include SCUBA diving, camping, gardening, geography, current events, and politics.

Upon graduating, Harris's career objective is to work in local, state, or federal government, environmental consulting, private industry, or university teaching and research. He prefers to stay in Florida but is willing to move elsewhere.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Donald A. Graetz

Donald A. Graetz, Chairman
Professor of Soil Science

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Dale R. Hensel

Dale R. Hensel
Professor of Soil Science

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Donald L. Myhre

Donald L. Myhre
Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jerry B. Sartain

Jerry B. Sartain
Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Salvadore J. Locascio

Salvadore J. Locascio
Professor of Horticultural Science

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August 1990

Jack L. Fry

Dean, College of Agriculture

Dean, Graduate School